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NITROGEN OXIDE AND VOLATILE ORGANIC COMPOUNDS ABATEMENT COST STUDY

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VOLATILE ORGANIC COMPOUNDS
ABATEMENT COST STUDY

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EXECUTIVE SUMMARY

This report presents the results of a study to estimate the costs of reducing emissions of NO_X and VOCs from stationary or point-sources such as petrochemical producers, oil refineries, and thermo-electric generating plants in Sarnia and the Hamilton-Toronto-Oshawa metropolitan regions. The specific objectives of the study were to:

- determine the major stationary sources and quantities of NO_X and VOCs emissions in Ontario and the study regions;
- project future emissions for the specified sectors and regions;
- identify abatement technologies and systems to reduce NO_X and VOCs emissions from stationary or point sources in the study regions;
- estimate capital and operating costs for applicable technologies for each source and use these data to develop abatement cost functions for stationary sources of NO_x and VOC emissions in the study regions;
- estimate the costs of achieving three abatement scenarios by stationary sources in the study regions.

The study team utilized the *Ontario Emissions Inventory System* of the Ministry of the Environment, as it was constituted in 1988, to determine emission levels for a "base case" year, 1985, by industrial sector, for sources within the study regions. These "base case" emissions serve as the basis for forecasts and emission reductions that could be achieved by various technology combinations.

Based on the Ministry's Emissions Inventory in 1988, point-source NO_x emissions for 1985 totalled 176 700 tonnes per year for the province and 74 400 tonnes per annum for the study regions. Point-source VOC emissions are estimated at 71 200 tonnes per year for the province and 56 500 tonnes per year for the Sarnia and the Oshawa-Toronto-Hamilton study regions. Point or stationary sources accounted for an estimated 32% of total NO_x and 10% of all VOC emissions for the province.

Emission forecasts were prepared for the three stationary source sectors which generate the bulk of NO_x and VOC emissions in the study regions: petrochemical producers, petroleum refineries and electric generating stations. Total NO_X emissions generated by plants in these 3 industrial sectors in the geographic regions under analysis were 54 500 tonnes per year in 1985, as documented by the Ontario Emissions Inventory System. In the absence of any new regulatory requirements, NO_x emissions from these three industrial sectors are projected to fall to 50 000 tonnes a year by 2010, due largely to responses by Ontario Hydro to the *Countdown Acid Rain Program.*

VOC emissions for the three point-source industrial sectors located in the study region being forecast were 38 390 tonnes annually in 1985 and are projected to rise to 70 500 tonnes a year by 2010 in the absence of new emissions regulations.

Seven different technologies for reducing or controlling VOC emissions were applied to identified VOC emission sources: catalytic incineration, thermal incineration, carbon treatment, steam flares, floating roof tanks, piping, and increased maintenance. Six technologies for reducing or controlling NO_X emissions were applied to the sources: low excess air firing, selective catalytic reduction, selective non-catalytic reduction, fuel switching, staged combustion, and low NO_X burners.

For a representative subset of establishments, detailed capital and operating costs and contaminant reductions were estimated, based on the application of pertinent technologies. Costs for other source establishments for which necessary technical data were lacking were estimated by extrapolation.

Costs and contaminant reduction estimates were used to derive abatement cost functions for each pollutant and by industrial source sector according to three selected scenarios:

- lowest achievable emission rate (LAER) at all sources;
- a minimum control level, specified as a percent reduction, applied to all sources;
- least-cost of control.

Owing to data limitations, cost and contaminant reduction estimates could be developed only for a subset of point-sources in the study regions.

In the case of VOC emissions, "controllable" point sources whose emissions total 23 200 tonnes per year could be reduced to a LAER level of control of 3 669 tonnes per year, at a cost of $22.4 million per year (at 10% interest) or $1 145 per tonne removed in 1986 $. Under a least-cost scenario, "controllable" VOC point source emissions could be reduced by 50% for about $145 per tonne removed.

The LAER level of abatement for NO_x in the study areas would reduce the "controllable" subset of point-source emissions from 47 922 tonnes to 23 500 tonnes per year, at a cost of $319.8 million per year or $12 100 per tonne, considerably higher than removal costs for VOC.

A reduction of NO_x emissions by 40% or better at each "controllable" point-source emitter could be achieved in the study areas at an annualized cost of $61.9 million per year or $3 200 per tonne removed. Under a least-cost control strategy, a reduction of 50% of emissions could be achieved for about $6 800 per tonne.

Based on these analyses, VOC control at point sources is considerably less expensive per tonne reduced than reductions at point sources of NO_x.

1 Introduction

> *Government, industry, academic and other non-government organizations should develop new tools and improve existing tools which achieve more efficient and effective environment-economy interaction.*
>
> \- *Recommendation 1.1 of* The National Task Force on Environment and Economy

One of the tools of economics that has proven most useful as an input to environmental policy is the abatement cost function. These cost functions are quantitative relationships between reductions in discharges of contaminants and abatement costs. The functions summarize information that is essential for assessing the economic costs imposed on sources of pollutants by regulation and for anticipating the reaction of these sources to regulation.

Abatement cost functions can also be used to determine the least cost means of achieving environmental protection objectives and to estimate the additional cost of regulatory strategies which are designed to meet objectives other than simple cost minimization.

During the past 15 years, the Ontario Ministry of the Environment has recognised the value of abatement cost functions and has been involved, directly and indirectly, in many studies where these functions have been developed. Now, as part of the development of a strategy for the control and abatement of oxidants, abatement cost functions have been developed for nitrogen oxides (NO_x) and volatile organic compounds (VOC's). Cost functions have been estimated for petrochemical producers, oil refineries, and thermo-electric generating plants in Sarnia and the Hamilton-Toronto-Oshawa metropolitan regions and used to estimate the total costs of achieving three abatement scenarios determined in consultation with Ministry officials. The costs have been developed in such a way that additional scenarios can be developed and tested fairly readily.

The structure of the report is as follows:

- Chapter 1 is this introduction.
- Chapter 2 reviews sources and emissions of NO_x and VOCs, and estimates how these factors will vary over time with changing levels of economic activity, and the Countdown Acid Rain program.
- Chapter 3 reviews technological options for controlling VOC and NO_x emissions.
- Chapter 4 discusses the procedures used to estimate costs of implementing emission controls on the significant point source emitters of NO_x and VOCs.
- Chapter 5 describes the methodologies developed for estimating abatement cost functions.
- Chapter 6 presents estimates of the costs to industrial point-sources of NO_x and VOC of implementing the available control technologies according to three implementation scenarios.

2 Present and Projected Sources of NO_X and VOC Emissions

This chapter enumerates current, point-source emissions of NO_X and VOCs, as estimated by the Ministry of the Environment, and applies forecasts of economic activity to estimate how these might be expected to change over time. Area sources, which include emissions from cars and trucks and account for over two-thirds of provincial NO_x emissions and over four-fifths of provincial VOC emissions, are not addressed in this study.

2.1 Existing Sources of NO_X and VOCs

Photochemical oxidants have long been recognized as a cause of vegetative, material, and human health damage. Agricultural crop damage in Canada was first attributed to ozone with the observation of tobacco 'weather fleck' in Southern Ontario in 1955 (MOE 1984). High concentrations of photochemical oxidants have also been observed to cause damage to certain materials, add to atmospheric haziness, and cause health damage to humans.

Photochemical oxidants are a class of secondary pollutants produced under solar radiation from volatile hydrocarbons and nitrogen oxides. The main oxidants produced by this chain of photochemical reactions include ozone (O_3), peroxyacetyl nitrate (PAN), and nitrogen dioxide (NO_2). While ozone is the principal oxidant produced by this process, it is less toxic than both PAN and NO_2 in some effects.

The time taken to produce these oxidants (from less than one hour to several days) has led to greater consideration of the impact of long range transportation of the emissions associated with this process in order to identify precursor sources and damages. The economic value of potential increased crop production from ozone reduction was estimated at about $15 million (1980$) per year for Ontario alone (MOE 1984).

Efforts to reduce ozone levels have concentrated on the control of anthropogenic precursor compounds: volatile organic compounds (VOCs), comprising both methane and non-methane hydrocarbons, and nitrogen oxides (NO_x).

2.1.1 A Note on Terminology

Sources of emissions can be grouped into a number of different categories:

Anthropogenic, or man-made, emissions are those resulting from human activities and include combustion and incineration, industrial processes, landfill emissions, emissions from the use of chemicals, fugitive emissions from various activities and materials. Non-anthropogenic, or *natural*, sources include those from natural fires, wildlife, and natural decomposition.

Anthropogenic sources fall into three major categories: mobile, stationary industrial, and other. *Mobile* sources include automobile combustion, other motor vehicles, agricultural and construction equipment and machinery, airplanes, trains, and marine vessels. *Stationary* industrial sources include combustion of hydrocarbons for industrial purposes, including power generation, emissions from a variety of industrial processes, and fugitive emissions from the processing, storage, and use of petrochemicals and chemical products. Other emissions result from combustion, the storage and use of chemicals and solvents, landfills, and miscellaneous sources.

In this report:

- *Process* refers to an industrial production process which leads to emissions of NO_x or VOCs. Emissions from point-sources often come out of *stacks* and multiple processes may lead into one stack or one process may lead into multiple stacks.
- *Establishment* and *plant* are used interchangeably and refer to a collection of unified production process at a single geographic location. *Company* or *firm* are also used interchangeably and refer to the corporate controlling entity operating one or more establishments or plants.
- *Source* refers to the emission point-source, often a stack, as identified by the *Ontario Emissions Inventory System (OEIS)* and is the most basic record unit in this database. Where multiple processes lead into one stack, the source is the same as the process; where a single process leads into multiple stacks, the source is the same as the stack.
- *Efficiency* refers to the emission removal capability of the control technology.

2.1.2 The Ontario Emissions Inventory

The *Ontario Emissions Inventory System*, maintained by the Air Resources Branch (ARB) of the Ministry of the Environment, contains detailed emissions data on both *area* and *point* sources for five pollutants in the province, including NO_X and VOCs.

The differentiation between area and point sources is essentially determined by the method used in estimating emissions. Point sources refer to stationary industrial plants where gaseous emissions are discharged from stacks or as fugitive emissions from buildings or storage areas. Point source emissions may be measured with stack testing devices or estimated with a degree of accuracy using mass balance techniques. Area sources include all other stationary or mobile sources for which estimates are based on geographic statistical data. This study is restricted to an analysis of control costs for point sources that are located in the study areas.

Inventories have been developed for base years of 1973, 1980, and 1985. In addition, since 1982, emissions data have been collected on an annual basis from the large, point-source emitters to update the Inventory (ARB, 1988). An international effort is under way to develop a common inventory of base case emissions for 1985. This Inventory is also being revised and updated constantly so that emission values for different contaminants and different sectors will vary over time.

Point Source Emissions Data

As of this writing, emissions data and estimates in the Inventory for about 50 % of the NO_X and VOCs point-source emitters have been updated to 1985. Emissions data for the remaining sources were obtained in 1980 or 1973 and have not been updated. The 1985 survey was conducted on a stack ("source") basis; earlier surveys provide data and estimates on a plant basis. Consequently, emissions data from previous surveys incorporated into the 1985 database have been pro-rated across a plant's stacks.

Estimates of point-source emissions are based on several different methods. Plant-specific estimates are used if available; otherwise, ARB applies US EPA-recommended emission factors to estimate emissions on the basis of production data collected by the Ministry. In some instances, the emission factors and methods used for similar processes are different as not all have been revised.

As of the end of 1988, ARB had not carried out an analysis of the reliability of its database; however, it does have estimates of the accuracy range of the methods it has used to estimate emissions for many of the sources and plants. Reliabilities vary depending on the pollutant and the emission source. The US EPA estimates a ±30 % range on its NO_x emission estimation procedure for point-sources. The estimated error range for VOC emissions estimates is up to ±50 % (ARB, 1988). In addition, there may be errors in the survey or production data provided.

2.1.3 The Study Regions

Two study regions were selected by the Ministry of the Environment to include major stationary sources of nitrogen oxides and volatile organic emissions in the province and areas where ozone levels have exceeded the Ministry of the Environment's ambient air quality guidelines.

The specific boundaries for the study regions were selected to correspond as closely as possible to municipal and county boundaries in order to facilitate any subsequent comparison of data. The municipalities and counties included in the study regions are Lambton, Hamilton-Wentworth, Halton, Peel, Metropolitan Toronto, York, and Durham. The study regions do not correspond exactly to the political jurisdictions because the UTM grid lines do not follow municipal boundaries. A list of the UTM grid cells included in each municipal division and a map showing the study regions are provided in Appendix B.

The Ontario Emissions Inventory contains emissions data for 41 industrial establishments in the petroleum refining and coal products and chemical products industries in the study region. Ontario Hydro's two generating stations that are located in the study areas, Lakeview and Lambton, bring the total number of establishments to 43. The 41 establishments in the petroleum refining and coal products and chemical products industries comprise 460 individual sources (or stacks) of NO_X and/or VOC emissions. Sources are identified by industrial process (including combustion or fugitive emissions) rather than by specific stacks because many stacks have multiple processes leading into them or sources (e.g., fugitive emissions or storage of volatile materials) may not be connected to a stack.

2.1.4 Nitrogen Oxide Emissions

As of the end of 1988, a total of 558 000 tonnes of NO_x were estimated to be generated in Ontario during 1985 by point and area sources combined. Point or stationary-source emissions amounted to 32% of total Ontario emissions. Area source emissions are generated by automobiles and trucks, which account for 45% of total Ontario NO_x emissions, off-highway vehicles (8.5%) and diesel railroad engines. These estimates and data were found in the Inventory during 1988 but may differ from revised and updated values currently residing in the Inventory.

As of this writing, point-source emissions of NO_x in the study regions during 1985 amounted to 74,400 tonnes per year as summarized in Table 2-1.[1]

---

[1] The sectoral aggregation used throughout this study is described in Appendix A. It differs somewhat from the aggregation used by the Air Resources Branch of the Ministry of the Environment, which is presented in Appendix C.

The predominant stationary sources of NO_x in Ontario are fossil-fuelled electric generating stations which emitted an estimated 94 600 tonnes of NO_x in 1985, 53.5% of the provincial point-source total. The largest single emitter in the Inventory database is Hydro's Nanticoke generating station on Lake Erie which emitted about 59 800 tonnes of NO_x in 1985 and 75 100 tonnes in 1983 (Hydro 1988a, p.3-9). Since 1985, Nanticoke has had low NO_x burners installed on all units, thus reducing the plant's emissions by about 35% from what they would be without controls. However, the Nanticoke generating station does not fall within Sarnia or Oshawa-Toronto-Hamilton regions and so has not been included in the present study. The next largest emitters of NO_x are the Lambton and Lakeview generating stations which account for virtually all the remaining NO_x emissions for this industry. These two plants are located in the Sarnia and Toronto regions respectively.

Petroleum refineries constitute the second largest group of industrial point-source emitters of NO_x in Ontario, with more than 10% of 1985 estimated emissions for the province and 26% for the study regions. Over 90% of the petroleum industry's emissions also emanate from the Sarnia and Oshawa-Toronto-Hamilton regions. Electric utilities (excluding the Nanticoke generating station), petroleum refineries and chemical plants in the Sarnia and Toronto-Hamilton regions are the source of approximately 66% of all point-source NO_x emissions in the province and about 73% of NO_x emissions from the study region.

As shown in Table 2-1, electric utilities in the study regions emitted an estimated 32 100 tonnes, petroleum refineries an estimated 19 600 tonnes and chemical plants an estimated 2 800 tonnes per year. Other significant industrial sources in the study regions include primary metal and fabricating at 8 100 tonnes (mostly Stelco in Hamilton), and the non-metallic minerals sector at 6 700 tonnes.

Over half of the point-source NO_x emissions in the study regions (about 39 000 tonnes per year) originate in the Sarnia/Lambton area with most of these coming from the Lambton generating station together with petroleum refining and coal products plants.

As indicated in Table 2-1, about 28% of the NO_x point-source emissions in the study area is released in the Toronto region, principally from the Lakeview generating station.

2.1.5 Volatile Organic Compound Emissions

Data and estimates of VOC's found in the Inventory during 1988 show that an estimated 749 500 tonnes of VOCs were generated in Ontario in 1985. About 90% of these emissions were produced by "area sources" which include automobiles and trucks (35% of the total) and fires or evaporation of paints and solvents (43%). Point-source emissions from all Ontario sources totalled about 71 200 tonnes per year during 1985 (1988 Inventory figures) while 56 500 tonnes were derived from point sources in the study regions. A more detailed sectoral and regional disaggregation are presented in Table 2-2.

As can be seen in Table 2-2, the petroleum refining and chemical sectors are the largest industrial point-source emitters of VOCs in Ontario, accounting for 68% of the estimated 1985 study area annual total of 56 600 tonnes from all point-sources. Almost 99% of provincial VOC emissions from petroleum refineries and chemical producers come from plants located in the study regions. Consequently, the petroleum refining and coal products and the chemical industries in the study region account for 54% of total point-source VOC emissions in the province, according to the Ontario Emissions Inventory. All of these emission values are subject to revision and updating.

Almost 80% of the total provincial point-source VOC emissions are released from sources located in the study regions. The petroleum refining sector contributes 50% of the study regions' total annual emissions or 28 000 tonnes. Other significant sources are the chemical products sector (10 200 tonnes), wood and paper (4 300 tonnes per year), primary metals and fabricating (4 600 tonnes) and non-metal minerals (4 000 tonnes per year).

The Sarnia-Lambton area sources generated about 25 900 tonnes of point-source VOC annually, or 46% of the study regions' total. VOC emissions from Sarnia originate largely from the chemicals and petroleum refining and coal products industries.

As shown in Table 2-2, Toronto alone contributes 11 200 tonnes of stationary-source VOCs per year, of which 4 316 tonnes comes from the pulp and paper manufacturers, 3 500 tonnes from refineries and chemical plants and about 3 200 tonnes per year from other manufacturers. The two petroleum refineries located in Mississauga (Peel) emit 7 700 tonnes and one in Oakville (Halton) contributes about 2 300 tonnes annually. Other significant emitters include iron and steel plants in Hamilton, which contribute over 2 000 tonnes of VOCs annually and motor vehicle manufacturing in Oakville and Oshawa which emit about 2 000 tonnes through spray-painting of vehicles.

2.1.6 Summary

Petroleum refineries, chemical industries, and electric generating stations in the Hamilton-Toronto-Oshawa and Sarnia regions constitute the most significant regional and sectoral point-sources of NO_X and VOCs emissions in the province. As these regions are close to agricultural land and to major centres of population in the province, they represent prime areas to examine the costs of control of oxidant precursor emissions in Ontario. The breakdown of emissions using this classification is presented in Table C-1 and Table C-2 for NO_x and VOC's respectively.

Table 2-1

1985 Point-Source NO_x Emissions by Sector and Regions

Sector	Study Regions	Lambton	Hamilton	Halton	Peel	Toronto	York	Durham
				- Tonnes per Annum -				
Primary	0	0		0	0		0	0
Food Processing	1 256	27	143	0	0	1 086	0	0
Rubber & Leather	377	0	44	0	0	333	0	0
Textiles & Clothing	46	0	0	0	0	46	0	0
Wood & Paper	334	0	30	0	0	303	0	0
Primary Metal & Fabricating	8 085	0	1 939	5 568	0	568	6	4
Machinery & Vehicles	483	0	152	265	0	65	0	0
Electric Products	222	0	100	0	0	117	5	0
Non-Metal Minerals	6 656	2 920	788	0	0	2 475	0	473
Petroleum Refining	19 574	15 320	84	1 153	2 850	167	0	0
Chemical Products	2 789	2 111	147	0	0	527	3	0
Misc. Manufacturing	24	0	0	0	0	21	2	0
Construction	0	0	0	0	0	0	0	0
Transport & Communication	183	0	0	0	0	183	0	0
Electric Utilities	32 104	18 458	0	0	0	13 646	0	0
Other Utilities	586	0	205	0	0	380	0	0
Trade	120	0	0	0	0	120	0	0
Services	1 535	81	458	0	0	949	17	31
TOTAL	74 371	38 918	4 090	6 986	2 850	20 986	33	508

Notes:

Data were aggregated from the 1985 Ontario Emissions Inventory as of 1988 according to sectoral categories and regional boundaries as defined in Appendix A of this report. Provincial NO_x point-source emissions for 1985 total 176 686 tonnes per year.

Table 2-2

1985 Point-Source VOC Emissions by Sector and Regions

Sector	Study Region	Lambton	Hamilton	Halton	Peel	Toronto	York	Durham
			Tonnes per Annum-					
Primary	0	0	0	0	0	0	0	0
Food Processing	1 135	1	361	0	0	774	0	0
Rubber & Leather	355	0	295	0	0	60	0	0
Textiles & Clothing	3	0	0	0	0	3	0	0
Wood & Paper	4 316	0	0	0	0	4 316	0	0
Primary Metal & Fabricating	4 550	0	2 152	1 171	0	799	125	304
Machinery & Vehicles	2 403	0	601	1 730	0	71	0	0
Electric Products	43	0	2	0	0	41	0	0
Non-Metal Minerals	4 003	1 044	2 164	0	0	796	0	0
Petroleum Refining	28 020	15 585	96	2 292	7 688	2 359	0	0
Chemical Products	10 194	8 970	20	0	0	1 204	0	0
Misc. Manufacturing	611	0	0	0	0	593	18	0
Construction	0	0	0	0	0	0	0	0
Transport & Communication	9	0	0	0	0	9	0	0
Electric Utilities	178	124	0	0	0	54	0	0
Other Utilities	466	0	362	0	0	104	0	0
Trade	6	0	0	0	0	6	0	0
Services	222	181	11	0	0	26	0	4
TOTAL	56 514	25 904	6 063	5 193	7 688	11 213	144	308

Notes:

Data were aggregated from the 1985 Ontario Emissions Inventory as of 1988 according to sectoral categories and regional boundaries defined in Appendix A of this report. Provincial VOC point-source emissions totalled 71 188 tonnes per year during 1985.

2.2 Projections

Base case emission levels for 1985 that were identified in the previous section (as found in the Ontario Emissions Inventory during 1988) formed the basis of projections of NO_X and VOC emissions over the period 1990 to 2010 from specific industrial sectors. Forecasts were derived for three key industrial sectors located in the study areas: Chemicals (and petrochemical) producers, refineries and electric generating stations.

There are three sources of potential changes in the level of emissions:

- production changes,
- process changes,
- emission control and abatement measures.

Production Changes

Emissions can vary with levels of production, fuel consumption, and product mix. Other factors remaining equal, it is expected that emission levels are proportional to the level of production: that a 10% increase in production would result in a 10% increase in the level of emissions.

Long-term physical quantity and economic growth projections from Ontario Hydro were the only projections available at the level of detail required for this study and so were used as a basis for the analysis (Ontario Hydro, 1988d). The Hydro projections are conservative in relation to Ontario manufacturing sector growth projected by Informetrica over the 1988 to 2005 period - an annual average of 2.9% compared to 3.5% projected by Informetrica (Informetrica, 1988).

Process Changes

The emission rate is also affected by changes in the production process. This includes both in-plant modifications to production processes and changes in material inputs. For instance, a switch from oil or coal to natural gas will result in lower NO_X emissions. These changes are difficult to assess directly and virtually impossible to predict. However, if accurate measures of emission levels and production levels at different times are available together with a measure of the efficiency of any control measures, then process changes will be responsible for any residual difference in emissions. Unfortunately, production data for 1980 emission levels were not available.

Stack Control Measures

Finally, emission levels may be controlled through the adoption of abatement technologies on stacks or which are aimed at reducing fugitive emission from storage areas and other sources. Efficiencies of different control technologies vary depending on production processes, emission levels and individual stack characteristics. The adoption of emissions control is largely influenced by regulation. However, emissions of a particular compound may also be strongly affected by control measures aimed at reducing emission levels of other compounds.

Data on removal efficiencies of any control technology in place at sources listed in the MOE inventory are often inconsistent and were acknowledged by ARB officials to be unreliable. Consequently, removals achieved by existing controls could not be verified or accurately analyzed using this database.

The influence of these three factors on historical changes in the level of NO_x and VOCs emissions in each of the industrial sectors is discussed below in the following sections for each industry.

2.2.1 Petroleum Refining and Coal Products (OSIC 3650, 3651, & 3690)

Long-term growth in the petroleum refining and coal products sector is expected to be modest due to considerable uncertainty about oil prices and competitive pressures. Firms have absorbed substantial drops in crude oil prices in recent years without a proportionate lowering of retail prices. Consequently, most firms in this fairly concentrated sector are in stable financial health and in a strong position to weather future fluctuations. The only major capital investment project presently under way in this sector is an expansion by Texaco of their Nanticoke refinery - outside the study region.

At an average growth of 2.3% a year, output from this sector is forecast by Ontario Hydro to lag behind the 2.7% real growth projected for the province as a whole over the 1988 to 2010 period (Ontario Hydro, 1988d).

NO_x Emissions

The petroleum refining and petroleum and coal products sector of the Oshawa-Toronto-Hamilton-Sarnia regions accounts for 26% of the estimated total point-source NO_x emissions in the study area and 11% of all estimated point-source emissions in the province. Over the 1980 to 1985 period, NO_x emissions from refineries located in the study regions declined by 20%, from 24 600 tonnes a year to 19 600 tonnes a year, according to MOE Inventory figures. This reduction paralleled a decline in output of refined petroleum of 15% and a decline in input of crude oil of 17% by Ontario refineries between 1980 and 1985 (Woods Gordon 1987). Output in dollar values for this sector declined by 12% over 1980 to 1985 (ibid). The inventory data and estimates do not reflect adoption of control technologies for NO_x among refineries except for the introduction of control measures for one firm in the non-refining part of this sector. This appears to have resulted in a 5% drop of emissions for the sector - 1 100 tonnes.

This analysis suggests that virtually no reductions in emissions were accomplished by process or input changes. Estimated reductions in emissions over the 1980 to 1985 period can be explained by changes in the level of production and the installation of abatement technologies. The extent to which process and input changes are likely to contribute to future reductions in emissions depends on the perceived regulatory policy pressures felt by firms as well as on economic determinants.

Projections of NO_x emissions from this sector are shown in Figure 2-1. Analysis over the 1980 to 1985 period has revealed negligible reductions resulting from process changes in this sector and consequently, potential reductions from such changes have not been included. The projections are based on growth rates derived by Ontario Hydro and applied to 1985 emission levels (Ontario Hydro, 1988d).

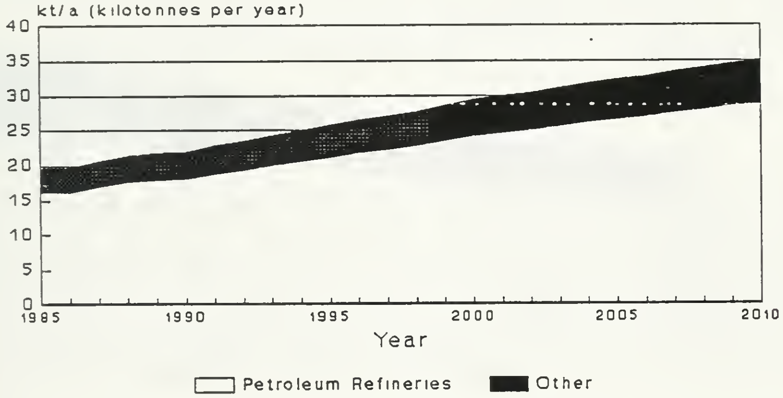

Figure 2-1

Projected Emissions of Nitrogen Oxides -- Petroleum and Coal Products 1985 - 2010.

VOC Emissions

Petroleum refining and coal products plants are the source of 50% of the estimated point-source VOC emissions in the study regions and 39% of the total estimated point-source emissions in the province.

According to the Ontario Emissions Inventory during the time of this writing (1988), annual emissions for this industry in the study regions increased by 115% from 13 000 to 28 000 tonnes between 1980 and 1985. This "growth" does not appear to reflect production changes and so may be considered largely statistical and attributable to improved estimates of VOC emissions in the study areas.

Projections of VOC emissions for 1985 to 2010 are shown in Figure 2-2. These estimates were derived by applying Ontario Hydro's forecasted growth of output in this sector to 1985 emission levels (Ontario Hydro, 1988d).

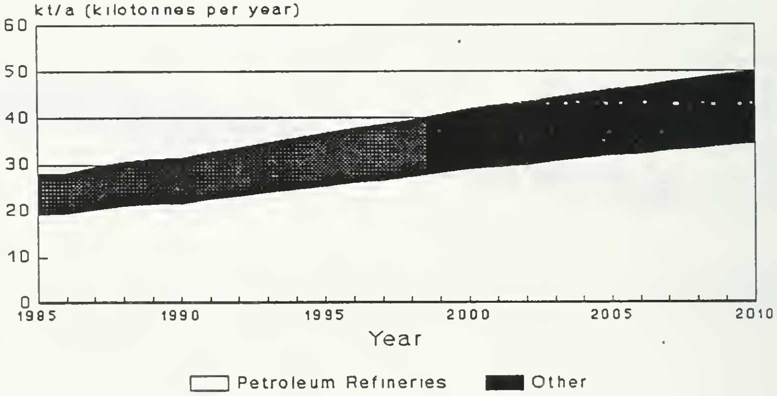

Figure 2-2

Projected Emissions of VOCs -- Petroleum and Coal Products 1985-2010.

2.2.2 Chemical Products Industries (OSIC 3720 TO 3790)

The chemical products sector encompasses a broad spectrum of products and producers. The Ontario Emissions Inventory lists 25 firms in this sector for the regions under study, with one firm in the mixed fertilizer subsector (OSIC 3720); five firms in the plastics and synthetic resins subsector (3730); two firms in the pharmaceuticals subsector (3740); seven firms in the paint and varnish subsector (3750); four firms in the soap and cleaning compounds subsector (3760); three firms in the industrial chemicals subsector (3780); and four firms in other chemical industries (3790).

Industrial production of chemical products in Canada grew by 11% from 1980 to 1985 while the nominal value of output increased by 15% for Ontario (ARA 1987, Table 2-5; Statistics Canada 31-003). Changes in emission levels resulting from this increase in the level of production are not reflected in the inventory data. This may be because the inventory data for firms in this sector have not been revised for establishments in the study region or because emissions did not rise concurrently with production. If the latter is correct, it is likely that process changes or control measures have been instituted over the intervening years.

Ontario Hydro projects output from this sector to grow at an average of 2.8% a year from 1988 to 2010 (Ontario Hydro, 1988d). This is close to the average forecasted by Ontario Hydro for growth in total provincial output of 2.7%. Growth of output over 1988 to 2005 is projected at 3.0 %, also below Informetrica's forecast of 3.5% for Ontario manufacturing over the same period (Informetrica, 1988).

NO_X Emissions

The 26 establishments that represent this sector in the study area account for only 4% of point-source NO_X emissions in the study region and 1.6% of all point-source emissions in the province. The Ontario Emissions Inventory indicates that the annual level of emissions dropped by 48% over the 1980 to 1985 period, from 5 400 to 2 800 tonnes. About 90% of this sharp drop in emissions is due to a 2 350-tonne decline from one source to which control measures appear to have been applied. No change in emissions was registered for over half the plants in this sector, either because no changes in emissions have occurred or because estimates have not been updated.

Records indicate that three plants in this sector installed control measures. However, reduction in emissions appear to have occurred in only one of these facilities.

Projections of NO_X emissions for 1988 to 2010 are provided in Figure 2-3. These estimates are exclusive of any anticipated process changes, the effect of which has been impossible to measure over past years. These estimates are also independent of any effects resulting from additional control measures.

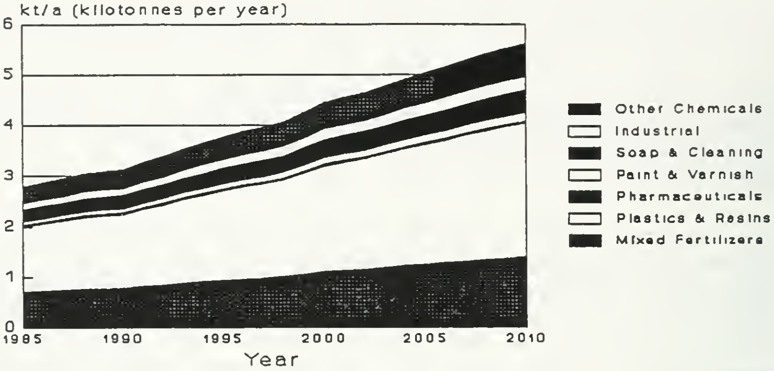

Figure 2-3

Projected Emissions of Nitrogen Oxides -- Chemical Products 1985-2010

VOC Emissions

The chemical products sector accounted for 18% of the estimated point-source emissions of VOCs for the study regions in 1985 and for 14% of the total for the province. The emissions inventory shows an increase from this sector of 9 800 tonnes, a rise of over 600% from 1980 to 1985. Most of this increase is attributable to improved estimates for a small number of large producers in the sector.

Without accurate data on changes in control technologies and efficiencies, it has not been possible to derive estimates of the degree to which process modifications and input changes or variations in the level of production have contributed to changes. Figure 2-4 presents projections of emissions for this sector for the 1985 to 2010 period.

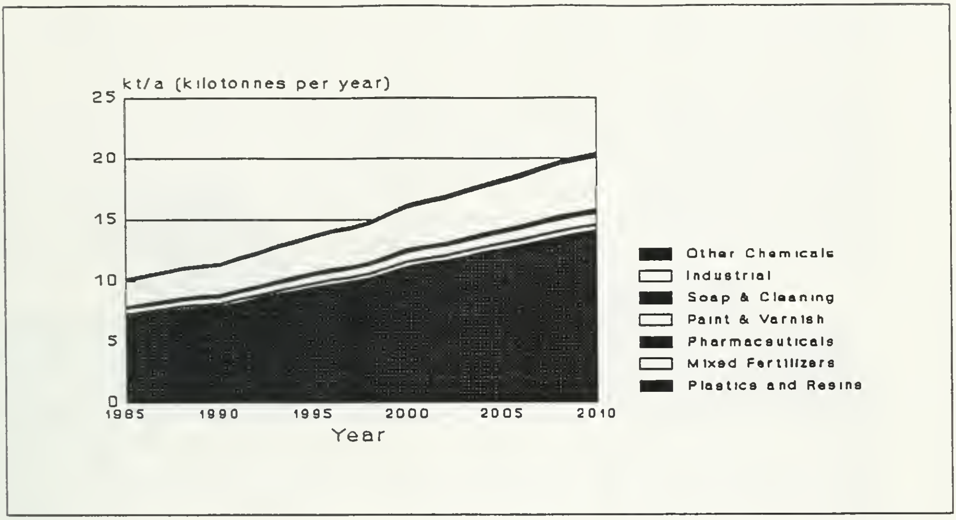

Figure 2-4

Projected Emissions of VOCs -- Chemical Products 1985-2010.

2.2.3 Electric Utilities (OSIC 5720)

The only electric generating stations in the study areas currently emitting nitrogen oxides or volatile organic compounds are Ontario Hydro's Lakeview and Lambton generating stations. In addition, records in the database show a small level of emissions from the Sarnia-Scott transmitting station in Courtright.

The R.L. Hearn generating station, active during the 1980 emissions inventory survey, is currently mothballed until 1989, at which point Ontario Hydro plans to permanently retire the station.

While growth in the electric utilities sector in Ontario is expected to average 2.2% over the 1985 to 2010 period (Ontario Hydro, 1988d), Ontario Hydro is bound by the *Countdown Acid Rain* program to limit its NO_x and SO_2 emissions. Ontario Regulation 662/85 limits total combined NO_X and SO_2 emissions and total SO_2 emissions from Hydro's fossil-fuelled generating stations. Assuming that Hydro's emissions of SO_2 are at the maximum permissible, the regulation sets limits of NO_X emissions of 60 kilotonnes from 1986 to 1989, and 40 kilotonnes thereafter.

Hydro is planning to use a variety of control options to meet these emission limits. Low NO_X burners were installed at all Nanticoke generating station units by 1988, reducing emissions by about 35% at the plant (Ontario Hydro, 1987, p. 54-56). Reductions from system levels will be further achieved by shifting power generation to units which have been retrofitted with low NO_X burners or which have low rates of NO_X emissions. Lakeview is projected to drop from an Average Capacity Factor (ACF) of 12% in 1986 to 4.1% in 1993, while Lambton is also expected to drop from an ACF of 57% in 1986 to 19.7% by 1992 (Ontario Hydro, 1988b, p. 3-10). Reductions in the annual consumption of coal (as indicated by the ACF) decrease NO_x and VOCs emissions by an comparable degree. However, under a high load growth scenario, conditions may call for the retrofitting of further units with low NO_X burners or the application of other forms of control technologies. Obviously, these are factors which are very difficult to project over the long-term on a plant-by-plant basis.

To forecast emissions from the Lakeview and Lambton generating stations, Hydro's five year operating forecast for individual plants was used for the period from 1988 to 1993 (Ontario Hydro, 1988c). For years after 1993, Lakeview and Lambton's proportion of total Hydro NO_X emissions for 1985 (adjusted to account for the reduction of emissions at Nanticoke due to the introduction of control technology) was pro-rated to Hydro's total allowable NO_X emissions as outlined under Ontario Regulation 622/85. Allowable NO_X emissions were considered to be the driving force for this projection as VOC emissions from these generating stations are relatively minor.

NO_X Emissions

Electric generating stations in the study area are responsible for 43% of the total NO_X emissions in the study areas and for 18.2% of the total NO_X emissions in the province. The study area excludes the single largest emitter of NO_X in Ontario - Nanticoke generating station - which emitted 75 kilotonnes in 1983 and an estimated 60 kilotonnes in 1985 or 29.5% of total point-source NO_X emissions in the province.

The Ontario Emissions Inventory indicates that from 1980 to 1985, emissions from Lakeview dropped by 31% while emissions from Lambton were reduced by 2.4%. Total NO_X emissions in the study area fell by 26% as a result of these factors and with the mothballing of the R.L. Hearn generating station. This substantial reduction in emissions is directly attributable to a change in the level of production (indicated by the ACF) at the generating stations. Projections of NO_X from electric utilities over the study period are detailed in Figure 2-5, according to the procedure explained in the preceding section. These levels drop off after 2006 to reflect Hydro's planned retirement of Lakeview generating station in that year (Ontario Hydro, 1987). These projections do not account for the introduction of NO_X control measures at these stations as none are currently proposed.

If low NO_X burners or other control technologies (including SO_2 controls) were applied to either of these stations, there would likely be an *increase* in the NO_X emissions from the station as Hydro would then shift production to these stations away from non-retrofitted units. The resulting increase in emissions would be 60% to 70% of the increased level of production at each plant less the reduction in emissions from the original production level. This paradoxical

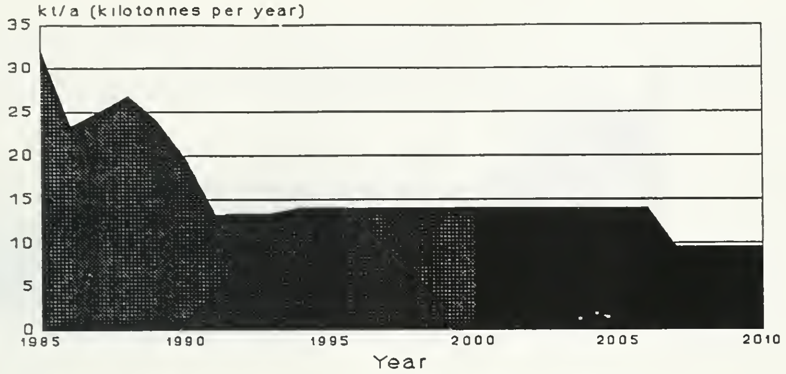

Figure 2-5

Projected Emissions of Nitrogen Oxides -- Electricity Generation 1985-2010.

result occurs because of the high capital cost of NO_x controls and because of significant excess capacity presently in this sector. For example, if two similar plants are operating at 50% capacity both generating the same amount of electricity, an equivalent level of reduction could be achieved by only retrofitting one plant and increasing its capacity utilization to 100% while mothballing the other plant as by retrofitting both plants. Retrofitting only one plant would cost only half as much in capital costs. If the removal efficiency of the control technology were 35%, total emissions from the plant now at full capacity would *increase* by 30% because production at this plant would have increased by 100% Total emissions from the two plants would have decreased by 35%, however.

As discussed above, long-term projections are sensitive to a host of factors and decisions which are very difficult, if not impossible, to predict. With only a small number of stations, the effect of these factors is much more important because they can no longer be considered random. Together with the lumpiness of capital investment at this scale, any long-term projections must be treated especially warily.

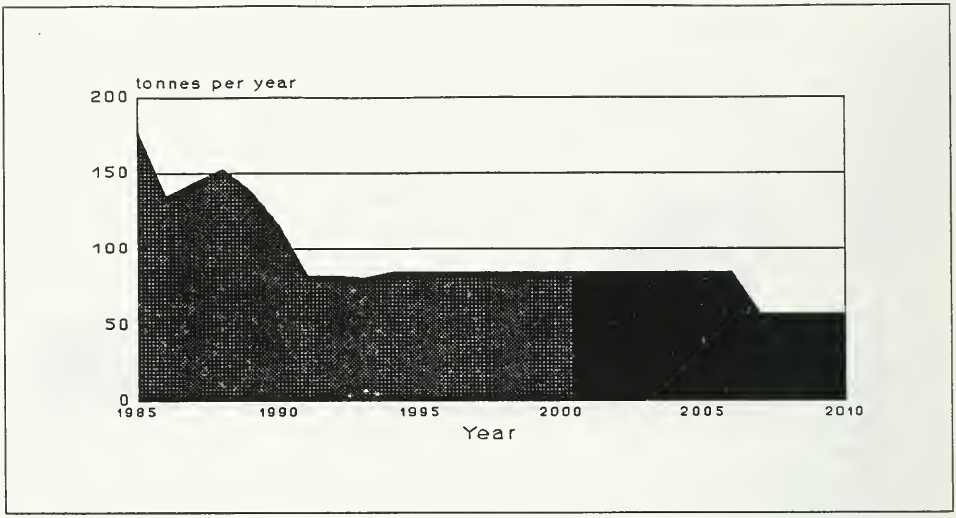

Figure 2-6

Projected Emissions of VOCs -- Electricity Generation 1985-2010.

VOC Emissions

Electric utilities are responsible for a very small amount of the total VOCs emitted in the province. Emissions in 1985 totalled 178 tonnes, only 0.34% of the 56 500 tonnes emitted by point-sources in the study regions and 0.2% of the 71 188 tonnes emitted from point-sources in the province. Estimated VOC emissions dropped by 80% from 867 tonnes in 1980 to 178 in 1985.

VOC emissions are projected to decrease gradually to the same degree as NO_x emissions and total coal use since no controls are presently anticipated. Estimates over the 1988 to 2010 period are presented in Figure 2-6 and, as with the NO_x emissions, reflect the planned retirement of Lakeview in 2006 and Ontario Hydro's system planning strategy to abide by the limits set out in Ontario Regulation 622/85. Installation of low NO_x burners would likely lead to an increased level of utilization of these plants and a consequent increase in VOC emissions.

2.3 Summary

Estimated NO_x emissions for point-source industrial sectors in the regions under analysis totalled 74 400 tonnes a year in 1985, according to estimates and data found in the *Ontario Emissions Inventory* in 1988. This total includes 19 600 tonnes per year from petroleum refineries, 2 800 tonnes from chemical products industries and 32 100 tonnes from electric generating stations.

In the absence of new regulations, NO_x emissions are projected to fall to 50 000 tonnes per year by 2010, due largely to SO_2 and NO_x reductions that are intended for electric power generating stations to comply with the *Countdown Acid Rain Program*. NO_x emissions are projected to fall to under 10 000 tonnes per year by 2010, based on a pro-rating of emissions from stations in the region to Ontario Hydro's total allowable emissions under Regulation 622/85 (the *Countdown Acid Rain Program*). However, emissions in 2010 from these stations could conceivably be much higher, depending on the generation capacity at each station, and on any control measures adopted for either NO_x or SO_2 emissions. By the year 2010, NO_x emissions from petroleum refineries are projected to rise to 34 900 tonnes and chemical industries to almost 5 600 tonnes.

According to the *Ontario Emissions Inventory* during 1988, total VOC emissions from establishments located in the study regions representing the three industrial sectors being forecast were 38 400 tonnes in 1985, comprised of 28 000 tonnes from petroleum refineries, 10 200 tonnes from chemical producers and 200 tonnes from electric utilities.

In the absence of new regulations, VOC emissions are projected to rise to 70 500 tonnes per year by the year 2010. Most of the increases are expected to come from petroleum refineries (50 000 tonnes) and chemical producers (20 500 tonnes).

3 Control Options

3.1 Volatile Organic Compound Control Technologies

Industrial emissions of volatile organic compounds mainly result from the production, storage, and use of synthetic organic chemicals. VOCs emitted from industrial sources are most commonly controlled by "add-on" control methods such as incineration (thermal or catalytic) and absorption. VOCs emitted by fugitive sources can be controlled by a combination of add-on and process technologies such as carbon treatment, improved maintenance, the installation of floating roofs on storage tanks, and piping improvements.

Control technologies are most usefully classified by their installation location. *Stack controls* are technologies which treat the combined flue gases from one or more processes using the same stack. *Process controls* are controls that are located at the process level and consequently do not affect emissions from other production processes using the same stack.

3.1.1 Thermal Incineration

Thermal incineration, a technology located at the stack level, uses a refractory chamber with burners as the combustion unit to incinerate VOC flue gases. A fan is used both to draw waste gases from the stack into the combustion unit and to provide excess air.

The mixing, temperature and retention time of the gases in the combustion unit determines the efficiency of combustion. With additional fuel used to heat the gases in the combustion unit, the efficiency of combustion can be increased to virtually 100% - the figure used in this analysis. This study develops costs of a system for maximum levels of combustion.

The expected lifetime of thermal incinerators is 10 to 15 years, with an average of 12.5 used in this study. Heat exchangers are widely used to recover heat from the incinerator flue gas in order to preheat waste gases or for use in production processes. Heat exchangers are expected to last for approximately 20 years.

3.1.2 Catalytic Incineration

Catalytic incinerators are also located at the stack level. The use of a catalyst (generally precious or base metals or their salts) rather than a flame allows oxidation at a much lower temperature than thermal incineration.

The efficiency of this control technology is determined by the type of catalyst used. Catalysts produced for two different efficiency levels - 90% and 99% - were costed for the appropriate stacks.

The incineration unit lasts for about 10 years while the catalyst must be replaced after about 5 years. The lower temperature levels required do not make heat exchange a viable proposition.

3.1.3 Carbon Treatment

In carbon absorption, VOCs passing through the stack are routed through a mass of porous carbon and bind to the surface due to surface tension. The method is used for low to medium concentrations of VOCs in the gas stream.

The efficiency of removal is close to 99.5% but decreases slightly as the carbon becomes more saturated with surface VOCs. Once the carbon surface nears saturation, it can be regenerated by steaming to a high temperature (the method considered in this study) or through vacuum methods. The absorbed VOCs are released from the carbon when heated through steam and can be collected, purified, and reused. A second carbon bed is required for use while the first is being regenerated.

The absorption unit lasts for 10 to 15 years (12.5 years assumed in this study), depending on corrosion and other factors. Over time, some VOCs remain on the carbon bed and after about five years it must be replaced to maintain removal rates.

Prices quoted for the recovery and sale by Anachemia Solvents Inc. for recovered VOCs from this process indicated that revenues were likely to be marginal and hence were not included.

3.1.4 Piping Changes

Fugitive emissions from some storage vessels can be controlled by piping modifications designed to send VOCs back to the source vessels. Temperature and pressure differences are reduced by piping improvements which help to close off the system and reduce emissions from working losses (described below).

VOC emissions are typically reduced by 98%, where applicable. The expected lifetime of these process improvements is 30 years.

3.1.5 Increased Maintenance

Additional maintenance of valves, pump fittings, and inspection for minor VOC leaks can also help to reduce fugitive losses at the process level. In appropriate cases, emissions can be reduced by 40%.

3.1.6 Flare Tip

A flare tip can be used to burn off VOCs at the stack level. Steam injection boosts the efficiency of removal by increasing the turbulence and retention time of the VOCs in the flame.

Efficiencies of flare tips vary, depending on air quantities, input concentrations, and other factors. With steam injection, the efficiency ranges from 80% to almost complete destruction. In this study, an average of 90% is assumed. A flare tip should last about 20 years.

3.1.7 Floating Tank Roof

Emissions from storage of organic chemicals with fixed roof tanks can occur from *breathing losses* or *working losses*. Breathing losses result from expansion and contraction of vapour caused by temperature and barometric changes. Working losses are emissions which result from filling and emptying tanks with resulting vapour discharges through the relief valve.

To reduce VOC emissions, either an external or an internal floating roof can be used. An external floating roof consists of a self-supporting roof with a seal on the surface of the liquid which slides along the walls of the cylindrical steel tank. An internal floating roof has both a permanent fixed roof and an internal deck which floats on the liquid surface.

Many of the tanks examined in the study already have existing floating roofs. The efficiency of reduction is about 75% and the lifetime estimated at 40 years.

3.2 Nitrogen Oxide Control Technologies

The main sources of NO_x from the industries studied are utility boilers, refinery heaters and boilers, and industrial boilers. Main control technologies for these sources include burner modifications, fuel changes, and flue gas treatments.

3.2.1 Staged Combustion

Staged combustion is a form of burner modification which is widely used to control NO_x emissions. The combustion air is divided into two or more streams. In the first stream, combustion occurs in a fuel rich environment (70% to 90% stoichiometric air) where the fuel is partially burned. The second stage injects air above the flame zone to complete the combustion. The lower flame temperature results in lower NO_x formation.

Staged combustion can reduce NO_x emissions by about 40%. The lifetime of the equipment is expected to be 20 years.

3.2.2 Low Excess Air Firing (LEA)

Low excess air firing reduces NO_x emissions by employing extensive mixing of air with fuel. Reducing oxygen inputs while allowing for complete combustion lowers the production of thermal NO_x. However, reducing excess oxygen levels also tends to diminish combustion efficiency and to increase emissions of carbon monoxide and particulates.

NO_x emissions can be reduced by 5% to 35% using this method, with an average of 20% assumed in this study. The expected capital lifetime of LEA equipment is 20 years.

3.2.3 Low NO_x Burners

Low NO_x burners are a type of boiler modification of particular interest to the power industry. NO_x emissions are reduced by employing a high degree of mixing and staging of combustion air. Low NO_x burners have already been installed on the eight units at Hydro's Nanticoke generating station, lowering projected emissions by 35%.

NO_x reductions from retrofitted burners are expected to average 30%. Low NO_x burners are expected to last for about 40 years.

3.2.4 Fuel Switching

Changing burner and boiler fuels from oil to gas with lower emission factors can typically reduce NO_x emissions by 50% to 70%, with 60% reduction levels assumed in this study. Converting from oil firing to natural gas requires a change in the firing mechanism of the heaters.

The attractiveness of such a conversion is, of course, highly dependent on the relative costs of the different fuels to the firm. Some companies, notably petroleum refiners, will have access to residual oil at a very low cost. For firms paying a larger proportion of the market price, conversion to natural gas.can represent a cost saving at these prices.

3.2.5 Selective Non-Catalytic Reduction (SNR)

SNR is a recently developed bottom-of-the-stack flue gas treatment for NO_x reduction on oil and gas-fired boilers. Injection of ammonia into the flue gas stream reacts with NO_x to form nitrogen and water. Disadvantages of this technology are that it can only be effectively operated at a temperature range around 1600° F.

This technique enables reductions of about 40%. A SNR system is expected to last for 20 years.

3.2.6 Selective Catalytic Reduction (SCR)

SCR is a bottom-of-the-stack flue gas treatment which uses a catalyst to reduce the temperature required to less than 800°F. Also a recently developed technology, the process has been applied to oil and gas-fired boilers. The process can be combined with combustion modifications when very high removal efficiencies are required.

SCR is the most effective NO_x stack abatement technology - achieving reductions from 40% to 90%, with an average of 55% assumed in this study. An SCR system should last for 20 years.

3.3 Summary

Assumptions and values for efficiencies and lifetimes used in cost estimation are summarized in Table 3-1.

Table 3-1

Control Technologies and Their Assumed Characteristics.

Technology	Controlled Compound	Control Location	Average Efficiency of Removal (%)	Estimated Lifetime (years)
Catalytic incineration	VOC	stack	90 or 99	10
Thermal incineration	VOC	stack	100	12.5
Carbon treatment	VOC	stack	99.5	12.5
Flare tip	VOC	stack	80	20
Floating roof tank	VOC	tank	75	40
Piping	VOC	process	98	30
Increased maintenance	VOC	process/tank	40	N/A
Low excess air firing	NO_x	process	20	20
Selective Non-cat. Red'n	NO_x	process	40	20
Selective Catalytic Red'n	NOx	process	55	20
Fuel change (oil to gas)	NO_x	process	60	20
Staged combustion	NO_x	process	40	20
Low NO_x burners	NO_x	process	30	20

Source: Calvert and Englund (1984), Chemical Engineering (1988), Electric Power Research Institute (1985), Freyling (1967), Oliver (1979), Ontario Hydro (1980), Perry (1973), Shreve (1967), US EPA (1985), and study team files.

4 Cost Estimates

This chapter discusses the procedures used to estimate costs of control for all significant sources of NO_x and VOC emissions in the study . Section 4.1 describes how a sample for detailed costing was selected and the methods used to cost these sources. Section 4.2 provides detail on specific assumptions used in estimating costs for each of the 13 control technologies considered. Finally, Section 4.3 explains how cost functions for industrial processes were estimated and used to extrapolate to the remaining sources not costed using the detailed method.

4.1 Costing Procedure

4.1.1 Methods

This section describes methods and assumptions used in this study to estimate the costs of control for alternative control technologies. To ensure consistency and accuracy in the estimates, costs have been estimated using methods similar to those outlined in the *Economic Analysis Branch (EAB) Control Cost Manual* (US EPA 1987). Exponents and co-efficients have been modified with values provided by Wadden (1987), Calvert (1984), US EPA (1984), Oliver (1979), and Perry (1973).

The estimating procedure is based on factored estimates and is suited for estimating control system costs for use in regulatory development. The procedure provides a clear disaggregation of capital cost into equipment, installation, and indirect elements and a disaggregation of operating costs into labour, maintenance, fuel, spare parts, and other components.

Only a selection of establishments comprising the major emitters for each industrial sector in the study could be costed using the detailed EAB-type methodology referred to above[2]. Costing using this method requires data on exit volumes or velocities which are lacking for a large number of the records in the database.

The final section in this chapter describes the extrapolation procedure used to estimate capital and operating costs for sources not costed using this detailed method. Details on specific control technology assumptions are provided below in section 4.2.

4.1.2 Sample Characteristics

Detailed capital and operating costs were calculated for significant NO_X and VOCs emission sources for five firms in the petroleum refining sector, 12 firms in the chemical products sector, and two electrical generating stations. These firms were selected with a number of considerations in mind:

- to provide the ability to extrapolate to non-selected firms: i.e., representing as broad a range of sectors and processes as possible,
- to include as large a share of the total study areas' emissions as possible,
- availability of the necessary stack data for detailed costing estimates.

The selected firms in the petroleum refining and chemical products sectors incorporate a total of 199 stacks comprising 231 individual sources (many stacks have multiple sources leading into them). Over 35 distinct industrial processes are represented in this group.

Costs were calculated on an individual source basis for the appropriate technologies and adjusted according to individual characteristics and production quantities.

Slightly over 75% of the total point-source emissions of NO_X and 50% of VOCs in the study regions are emitted by sources which were costed in this manner. This includes over 95% of both NO_X and VOCs emissions from the chemical products sector and all the emissions in the electrical generating sector. In the petroleum refining sector, sources responsible for 31% of NO_X emissions and 34% of VOCs emissions are included in this detailed costing. A higher proportion of the chemical industry emissions than petroleum refining industry emissions were costed using the detailed method as this sector represents a more heterogenous group of processes than the petroleum refining sector.

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[2] The database lacks the necessary stack data for detailed costing for some of the major emitters in each industry subsector and so the next largest emitters were chosen.

In cases where emissions and calculated concentrations are negligible, control costs were not estimated.

4.1.3 Considerations

Control technologies apply either at the process or stack level: costs of control for both types are estimated in this study. When control is at the stack level, emissions are reduced for all processes using the single stack. In some cases, both stack and process control technologies may apply to a particular source of emissions.

In a few instances, costs of control for stacks from identical processes within the same establishment were estimated together if the temperature, flow, and emission data indicated they were similar. A geometric mean of the flow and emissions data was taken and the mean values used to estimate a control cost for these stacks.

Costs are estimated initially for the cost of including controls in a new plant because each retrofit is highly site specific and costs may vary greatly. Additional costs of retrofitting controls to existing facilities are added as a proportion of total capital costs. Typical costs for retrofitting different control technologies are discussed below.

Capital costs are annualized at varying interest rates in the scenarios reported in Chapter 6 according to the estimated lifetimes for the technologies listed in Table 3-1.

Both capital and annual operating costs are estimated for each of the technologies considered below. Included in operating costs are labour, maintenance, electricity, fuel, spare parts, waste disposal, overhead, water, fuel savings, and other costs. Capital costs include indirect costs such as installation, engineering, and contingencies. Costs for sources at all except two facilities are calculated for continuous operation over 344 days per year. Two stacks at one facility were found to operate for only two hours a day as they were test booths while the others operated continuously. Another plant was found to operate for 16 hrs a day, five days a week, for fifty weeks in the year and was costed accordingly.

It must be emphasized that combinations of control technologies applied to one source were not considered in this study because of the large number of combinations possible. Levels of reduction could be increased in some instances by installing two or more control technologies at the same source. The associated reduction efficiencies and costs are complex to calculate and determined largely by site-specific circumstances. Costs to achieve a specific reduction target may be lower for these combinations in some instances than for alternative single systems.

While NO_x and VOCs technologies are not completely independent, they were treated as such in this study.

4.2 Technology Costing Assumptions

Control technologies were selected for application to sources identified in the emissions inventory on the basis of the industrial process indicated in the database and on the basis of other information obtained by the study team. Costs of applying each technology to a particular source were estimated from equations developed from the study team taking into account individual stack and process characteristics.

4.2.1 Volatile Organic Compound Technology Costing Assumptions

4.2.1.1 Thermal Incineration

Thermal incineration was costed for a design temperature of 870°C. Combustion equations and heat values are from Fryling (Fryling 1967). This stack process for VOCs was applied to 33 sources, comprising a variety of industrial processes and involving emissions of 7 300 tonnes annually.

4.2.1.2 Catalytic Incineration

Catalysts are very specific to the VOC being removed. The catalyst used for all cost estimates in this study is platinum supported on ceramic. As this common catalyst is recoverable in only up to 20% of usages and recovery revenues are marginal, they are not included. Heat recovery units were also not included in the costs as the suitability of these is very site-specific.

Catalytic incineration was costed for a design temperature of 510°C at efficiencies of 90% and 99%. Combustion equations and heat values are from Fryling (Fryling 1967). This stack process for VOCs was applied to 34 sources emitting an annual total of 7 400 tonnes. Processes include industrial uses and production of synthetic organic chemicals.

4.2.1.3 Carbon Treatment

Carbon treatment is commonly used for lower VOC concentration levels than justified for incineration methods. Costs for the absorber, custom unit, or stainless steel vessel (if the VOCs are considered corrosive) were calculated where appropriate.

Recovery costs and revenues quoted by Anachemia Solvents Inc. for a sample VOC (dichlorethylene) from the carbon treatment process were found to be only marginally profitable if at all and so were not included.

Cost estimates for this stack process were estimated for 22 sources, with industrial processes including the production, use, and storage of synthetic chemicals. These sources emitted an annual total of 4 480 tonnes in 1985.

4.2.1.4 Piping Changes

Capital costs for piping changes were taken from installed costs cited in Calvert and Englund (Calvert and Englund, 1984). Annual operating costs for painting, checking insulation, and maintenance of valves and seals were estimated at 10% of the capital costs. Five sources annually emitting a total of 630 tonnes were costed for this process change.

4.2.1.5 Improved Maintenance

Improved maintenance of valves, joints, pump glands, flanges and other equipment was estimated at two person years annually for large plants (such as refineries) and one person year for smaller plants. These costs were applied to two fugitive sources emitting a total of 2 080 tonnes.

4.2.1.6 Flare Tip

The petroleum refinery industry currently utilizes steam-tipped flares. This stack control was costed for two sources emitting a total of 20 tonnes a year.

4.2.1.7 Floating Roof Tanks

Floating roof tanks are also widely in use among the sample selected for costing. Cost savings are incurred in the conversion as a result of saved VOCs in the tank. Annual cost savings were added to operating costs to get net operating costs. If the annual costs savings were larger than annual operating costs, net operating cost becomes negative. In the five cases where floating roof tanks appeared not to be in use, costs were applied.

4.2.2 Nitrogen Oxide Technology Costing Assumptions

4.2.2.1 Staged Combustion

Costs for staged combustion are very sensitive to the nitrogen ratio of the fuel which can range from 0.04 to over 0.6. A value of 0.44 was selected to represent average costs. An analysis of the technology and nitrogen content of the fuels indicated that this process modification would only be applicable for oil burners. The technology was applied to 20 sources emitting 4 730 tonnes a year of NO_X.

4.2.2.2 Low Excess Air Firing

Another process change; low excess air firing, was also applied only to oil burners - the same 20 sources as above emitting 4 730 tonnes.

4.2.2.3 Low NO_x Burners

Low NO_x burners are used mainly in the electric generating industry, which has done its own cost analysis of control options for this sector. They were applied to two generating stations in the region.

4.2.2.4 Fuel Switching

A capital cost of $50 000 (1986$) per boiler was estimated to modify fuel injection so gas can be used with oil as a standby.

Operating costs are calculated as the difference between oil costs and costs for an equivalent BTU value of gas. For refineries, the cost of oil was considered to be negligible; in other situations, a ratio of the full price was used, depending on the firm's location and supply sources. The process was applied to 12 sources emitting 1 680 t/a. Fuel switching was not applied where the boiler is fired by waste process gas because of the high cost required to restructure the entire process.

4.2.2.5 Selective Non-Catalytic and Catalytic Reduction

Costs for both SNR and SCR processes were derived from estimates for a 500 MW generating station. Component elements of the operating cost were then extracted. Costs of disposal of catalyst (often containing hazardous materials) were included in operating costs. Both processes were applied to 75 different sources emitting a total of 7 500 tonnes a year, covering mostly oil and gas heaters and boilers but also including coal-fired generators.

4.2.3 Retrofitting Costs

Retrofitting of technologies to existing processes are not estimated for each source because of the highly site-specific nature of these costs. Instead, retrofit factors as a ratio of capital costs are applied to capital costs after these have been estimated for each site. Costs considered include:

- auxiliaries: ductwork, long runs, extra tees, elbows and other expensive fittings;
- handling and erection: may require special treatment for unloading, transport, and assembly;

- piping, insulation, and painting: increases in relation to amount of ductwork required;
- site preparation: could be lower than new facilities if site sufficiently prepared for original facility;
- facilities and buildings: potentially the largest component of costs as electrical and other demands may exceed existing capacity;,
- engineering and supervision: design of control to fit an existing facility typically requires additional engineering and supervision;
- lost production revenue: installation may necessitate a temporary shutdown of process or plant; and
- contingencies: because of additional uncertainty involved, contingency fund should increase.

Retrofitting of existing facilities increases capital costs by an average of 25% to 50% of capital costs for most control technologies. Retrofitting of selective catalytic reduction was estimated to result in an increase of capital costs of up to 75%. For purposes of this study, retrofit factors of 1.6 and 1.35 have been adopted for selective catalytic reduction and all other technologies respectively.

4.3 Estimation of Cost Functions

4.3.1 Method

Costs of control for facilities not in the sample selected for detailed costing were estimated by extrapolating for similar industrial processes costed using the EAB methodology described above.

The extrapolation procedure consists of two steps. First, capital and operating costs for each technology and industrial process were estimated by regressing these costs on production quantity (or emission level where production quantity is unavailable or inappropriate).

In many cases, production quantities were not available or appear incorrect. In numerous other cases, the production units were not comparable because other industrial processes are used as proxies for costing purposes. This was necessary because it was not possible to estimate detailed costs for all the different processes in the study regions.

Where possible, both linear and exponential functions were used to estimate process costs. Because of the large number of different industrial processes, in many cases fewer than three emission sources were available for estimation, often with the same level of emissions. In these cases only average costs or a straight linear function could be estimated.

Second, the co-efficients for each technology derived using this procedure were applied to the individual sources of each of the uncosted firms where production processes are similar.

4.3.2 Determination of the Sample

The selection of the sources which were costed in a detailed manner is described above in Section 4.1.2. Over 75% of the NO_x emissions and over 50% of the VOCs emissions from the three industries of concern in the study areas are from sources which were costed in this detailed manner. As reported in Section 4.1.1, the requisite data on exit volumes or velocities for estimating costs in this detailed manner was lacking for a large number of the sources in the database. Consequently, cost estimates had to be extrapolated to the remaining sources using the methodology described in the section above. Unfortunately, data for many of these remaining sources were incorrect, vague or missing.

Of the 229 emission sources included among these establishments as identified by the emissions inventory:

- 18 are industrial processes which are not clearly specified (the process name was "miscellaneous" or "undetermined"),
- 8 have since been closed, and
- 44 exhibit negligible emissions.

The remaining 159 sources are responsible for 7 785 t/a of NO_X emissions and 14,260 t/a of VOCs emissions. Hence, data limitations made it impossible to develop costs for 11% of total NO_X and 12% of total VOCs emissions in the study regions.

The total NO_x and VOCs emissions in the study sample - 47 922 tonnes per year and 23 198, tonnes per year, respectively - do not include these emissions for which it was not possible to derive costs of control.

Most of the emissions from the remaining sources were in the petroleum refining sector. As explained above, the industrial processes in this sector are more homogenous than those in the chemical products sector and so are more suited for extrapolation.

This extrapolated sample was then combined with the costed sample to form a complete database (except for the exclusions noted above) of capital and operating costs for each relevant control technology by individual source.

5 Abatement Cost Functions

5.1 Introduction

There are a number of potential strategies for regulating emissions of NO_x and VOC. Three scenarios were selected by the Ministry to estimate the costs of abatement:

- Lowest Achievable Emission Rate (LAER) scenario: requiring the use of technology which leads to the lowest level of emissions,
- Minimum Control Level on all sources scenario: requiring every emitter to reduce emissions by a fixed minimum percentage (or the lowest achievable rate if this level is not achievable),
- Least Cost scenario: requiring emitters as a group to implement the least-cost technologies to achieve a specified abatement target.

In this study, the LAER was selected from those technologies which applied to the industrial process from the set of thirteen control technologies examined. For instance, increased maintenance and piping changes apply to fugitive emissions but not to emissions from boiler processes.

The three scenarios above are identical when the Minimum Control Level and the Least Cost scenarios are set to maximum or 100% removal target levels. That is, the LAER scenario becomes a special case of the other two scenarios. This equality will provide a useful check on the calculations in Chapter 6.

Estimating abatement cost functions for these scenarios involved several steps:

- identification of the source sectors to be controlled, as described in Chapter 2;

- identification of the emission control technologies available to emitters of NO_x or VOCs, as discussed in Chapter 3;
- preparation of estimates of the costs of implementing these technologies for each process in each plant, as described in Chapter 4;
- identification of technologies to be selected under each of the three regulatory scenarios and the costs and emission reductions associated with these technologies;
- for the last two scenarios, where the level of control, and not the technology, is specified as part of the control strategy, estimation of how the cost of control varies with the level of control.

These five steps are discussed in the remainder of this chapter and examples using hypothetical data are presented.

5.2 Emission Control Technologies

Thirteen technologies were identified with the potential for controlling emissions of NO_x and VOC as described in Chapter 3. Different technologies are appropriate for different types of emission sources. For example, piping changes deal with fugitive emissions, but the incineration technologies deal with stack emissions. The selection of the best control technology for any particular circumstance will depend on the technical suitability of the technology, the emission reductions required by regulation, and the costs of adopting the various technologies. In the case of the first scenario (lowest emissions), cost is not a factor in selecting control technologies.

In the second scenario (requiring every emitter to reduce emissions by a fixed minimum percentage), the applicable technologies may be unable to meet the regulatory requirements for some sources. For these sources, the control technology applicable which leads to the lowest level of emissions is applied. Of the sources with applicable technology which can be controlled at the required level, the least expensive technology will be selected.

Finally, in the third scenario (requiring the least cost technologies across all sources to achieve a given target), the efficiencies and costs of all control technologies for all sources of emission must be considered at once.

5.3 Cost Estimates for the Scenarios

Costs of control for individual processes were estimated using either by detailed costing on a source-by-source basis, or by extrapolating estimates based on the EAB approach as described in Chapter 4. These costs were estimated for each industrial process, for each control technology which is technically suitable. No attempt was made to estimate the costs of non-compliance.

5.4 Technologies Selected

The algorithm for selecting technologies, and thereby estimating abatement costs and removal efficiencies, varies depending on the abatement scenario under consideration. The algorithm for each of the three scenarios considered, and example calculations are presented below.

Table 5-1

Example Calculation for Three Hypothetical Processes for Scenario 1 -- Adopt Technologies with the Lowest Technically Achievable Emissions

Source	Control Tech. Combo.	Orig. Emiss. (tonnes) a	Remov. Effic. (%) b	Emiss. Reduct. (tonnes) c=a*b	Control Cost (annual) d	Unit Cost ($ per tonne) d/c	Most Effic. Tech.	Total Reduct.	Cost
1	1	100	30	30	$1 320	$44			
1	2	100	50	50	$2 500	$50			
1	3	100	60	60	$3 400	$57			
1	4	100	70	70	$4 800	$69	4	0	$4 800
2	1	250	40	100	$4 000	$40			
2	3	250	50	125	$5 200	$42			
2	4	250	30	75	$4 500	$60			
2	2	250	56	140	$9 000	$64	2	140	$9 000
3	2	300	30	90	$7 000	$78			
3	1	300	60	180	$7 700	$43			
3	3	300	63	189	$10 000	$53			
3	4	300	65	195	$12 000	$62	4	195	$12 000
TOTAL		650						405*	$25 800

* Removal Efficiency = (405/650) = 62%

5.4.1 Scenario 1 -- Lowest Achievable Emission Rate

This scenario is quite straightforward. The selected technology is the technology that provides the greatest reduction of emissions at each source. Costs and emission reductions associated with each source are identified for the most efficient control technology and are summed, as indicated in the example in Table 5-1.

In this example, a 62% reduction in NO_X emissions is achieved at a cost of $25 800.

5.4.2 Scenario 2 -- Minimum Control Level on all sources

This scenario assumes that a minimum control level is applied to all sources of emissions. Applying equal control requirements is a common mean of regulating emissions. However, setting these as a percentage means that firms that have already implemented controls on emissions are subjected to a more stringent requirement than those who have not. This control scenario results in greater total costs of compliance than the Least Cost scenario.

Table 5-2

Example of approach used for Scenario 2 -- Minimum control level applied to all sources of emissions for hypothetical processes.

Minimum control level 40.0%

Source Tech.	Control Orig (tonnes) a	NOx Effic % b	Control Reduct. (tonnes) c=a*b	NOx Cost (annual) d	Control Cost d/c	Unit Cost	Adjusted Tech.	Select	Reduct.	Cost
1	1	100	0.3	30	$1 320	$44	1.0E+18			
1	2	100	0.5	50	$2 500	$50	2500	2	50	$2 500
1	3	100	0.6	60	$3 400	$57	3400			
1	4	100	0.7	70	$4 800	$69	4800			
2	1	250	0.4	100	$4 000	$40	4000	1	100	$4 000
2	3	250	0.5	125	$5 200	$42	5200			
2	4	250	0.3	75	$4 500	$60	4500			
2	2	250	0.56	140	$9 000	$64	9000			
3	2	300	0.3	90	$7 000	$78	1.0E+18			
3	1	300	0.6	180	$7 700	$43	7700	1	180	$7 700
3	3	300	0.63	189	$10 000	$53	10000			
3	4	300	0.65	195	$12 000	$62	12000			
TOTAL									330	$14 200

Removal Efficiency = (330/650) = 51%

The algorithm used to estimate costs and effectiveness of this control strategy involves assigning an arbitrarily high cost to control technologies with removal efficiencies below the required level, and then choosing the least cost technically feasible control technology for each process. Where no control technologies apply with efficiencies above the selected level, the technology with the highest removal rate is selected - which explains why in Chapter 6, applying a minimum control target reduction of 100% for VOCs results in an actual reduction level of 82%. This is illustrated in Table 5-2, which uses the same hypothetical sources to be controlled that were used in Table 5-1.

Where it is technically achievable, a scenario specifying a minimum control level will lead to reductions in excess of the minimum level, since removal efficiencies of control technologies cannot realistically be fine tuned to reflect the regulatory requirement. This is evident in Table 5-2. In this case, setting a minimum control level of 40% leads to a 51% reduction in emissions at a cost of $14 200.

The algorithm used can be applied repeatedly, using various minimum control levels, to generate a cost abatement curve. The curve for the indicated example is presented in Figure 5-1.

5.4.3 Scenario 3 -- Least Cost System Cost

In the third scenario considered, the mix of technologies applicable over the entire group of emitters which achieve a specific global reduction at the lowest cost is selected. This scenario indicates the most cost efficient means of achieving a specified reduction target in both regions, without considering who bears the costs of achieving this.

Estimating this cost requires a multi-step process. First, it is necessary to estimate the *incremental unit cost* of each reduction of emissions for each technology for each source.

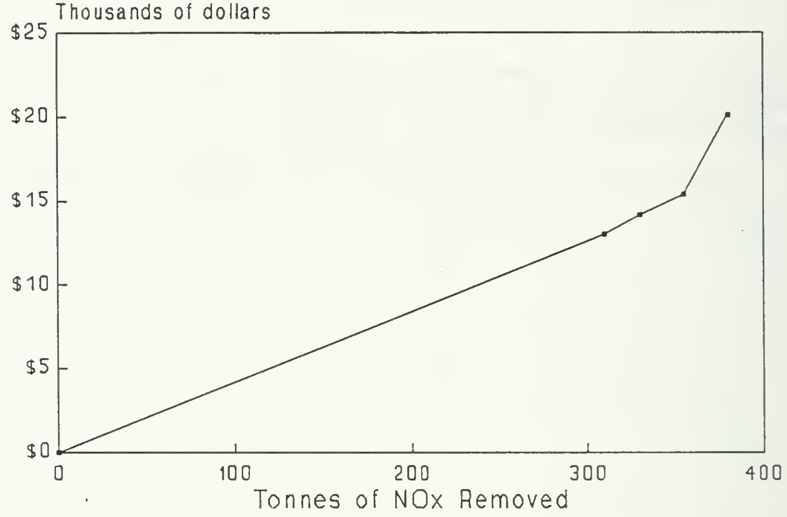

Figure 5-1

Abatement Cost Curve for Scenario 2 (Hypothetical Example).

To illustrate the concept of incremental unit costs, consider a single source emitting 100 tonnes a year of VOCs where two control technologies apply, one at a removal efficiency of 40% and costing $35 000 per year and the other at a removal efficiency of 75% and costing $100 000 per year. The *average costs* of control for the two technologies are easy to calculate and are $875 per tonne and $1 333 per tonne, respectively. However, the incremental unit cost is the total costs of control for the option less the total costs of control for the next less efficient option divided by the difference in reduction levels between these two options.

In algebraic notation, this is: $MC2 = (TC2 - TC1)/(Q2 - Q1)$ where MC2 is the incremental unit cost of the second least efficient technology, TC2 is the total annual costs of control for the second least efficient technology, TC1, the total costs for the least efficient technology, Q2 the emission reduction level for the second least efficient technology, and Q1 the reduction in emissions for the least efficient technology.

For the least efficient technology, the only less efficient option is that of no control at all, so the above equation yields an incremental unit cost which is equivalent to the average cost of control for that technology. For the second least efficient technology in the above example, the incremental unit cost is equivalent to ($100 000 - $35 000)/(75 - 40 tonnes) or $1 857 a tonne.

Once the incremental unit costs of all control technologies for all processes are estimated, these can be sorted, and cumulative reductions and costs associated with each unit cost can be calculated. The cost of the least-cost reduction is then the cumulative cost associated with the desired cumulative reduction.

There are two complications to this approach. First, there may be some control technologies for a particular process which are more costly but less efficient than other control technologies.[3] These are merely excluded from consideration.

Second, there may be technologies which achieve reductions at a lower incremental cost than less efficient and cheaper technologies. To ensure proper accounting for these, their incremental cost cannot be included directly. This is addressed by adjusting the incremental cost of the less efficient technology, and then removing this adjustment after the sorting and selection, if this is necessary.

These different cases are presented in Tables 5-3 and 5-4, using the hypothetical examples considered for the other scenarios. Process 1 is a straight-forward example of more efficient technologies having higher incremental unit costs. For process 2, control technology 4 is more expensive and less efficient than control technology 1, and is therefore excluded from the analysis. For process 3, technology 1 has an incremental unit cost below that for technology 2. Thus in the second iteration, an adjustment is made to the cost of technology 2 to bring it into line with that for technology 1. If the desired control level requires technology 2 but not technology 1 for process 3, the cost adjustment will be reapplied. Otherwise, the accounting will be correct even with this adjustment.

The incremental unit costs, cumulative reductions and costs, and cost adjustments are indicated in Table 5-4, and the resulting cost curve is presented in Figure 5-2.

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[3] These technologies may be attractive at different interest rates, different scales, or in particular site-specific circumstances which deviate from those implicitly assumed in the cost estimation.

Table 5-3

Hypothetical example for Scenario 3 -- Least cost technologies over the system

Iteration 1 **Iteration 2**

Source Tech.	Control Orig. (tonnes) a	NO_x Effic. (%) b	Control Reduct. (tonnes) c=a*b	NOx Cost (annual) d	Control Cost d/c	Unit Cost	Incr. Reduct.	Incr. Unit $	Incr. Cost per Unit Red.	Incr. Unit $	Incr.	Incr.
1	1	100	0.3	30	$1 320	$44	$1 320	30	$44	$1 320	30	$44
1	2	100	0.5	50	$2 500	$50	$1 180	20	$59	$1 180	20	$59
1	3	100	0.6	60	$3 400	$57	$900	10	$90	$900	10	$90
1	4	100	0.7	70	$4 800	$69	$1 400	10	$140	$1 400	10	$140
2	1	250	0.4	100	$4 000	$40	$4 000	100	$40	$4 000	100	$40
2	3	250	0.5	125	$5 200	$42	$1 200	25	$48	$1 200	25	$48
2	4	250	0.3	75	$4 500	$60	($700)	-50	$14	exc.1		
2	2	250	0.56	140	$9 000	$64	$4 500	65	$69	$3 800	15	$253
3	2	300	0.3	90	$7 000	$78	$7 000	90	$78	$3850	90	$43
3	1	300	0.6	180	$7 700	$43	$700	90	$8	$7 700	180	$43
3	3	300	0.63	189	$10 000	$53	$2 300	9	$256	$2 300	9	$256
3	4	300	0.65	195	$12 000	$62	$2 000	6	$333	$2 000	6	$333

1 Excluded because there exists a less expensive, more efficient control technology.

Table 5-4

Example of Least-Cost Scenario Table, Sorted by Incremental Unit Costs.

Increment Cost	Increment Reduction (tonnes)	Increment Unit Cost	Cumulative Cost	Cost Correction	Cumulative Cost	Cumulative Reduction (tonnes)	Reduction Percent
$4 000	100	$40	$4 000	$0	$4 000	100	
$3 850	90	$43	$7 850	$3 150	$11 000	190	29.2%
$3 850	90	$43	$11 700	$0	$11 700	280	43.1%
$1 320	30	$44	$13 020	$0	$13 020	310	47.7%
$1 200	25	$48	$14 220	$0	$14 220	335	51.5%
$1 180	20	$59	$15 400	$0	$15 400	355	54.6%
$900	10	$90	$16 300	$0	$16 300	365	56.2%
$1 400	10	$140	$17 700	$0	$17 700	375	57.7%
$3 800	15	$253	$21 500	$0	$21 500	390	60.0%
$2 300	9	$256	$23 800	$0	$23 800	399	61.4%
$2 000	6	$333	$25 800	$0	$25 800	405	62.3%

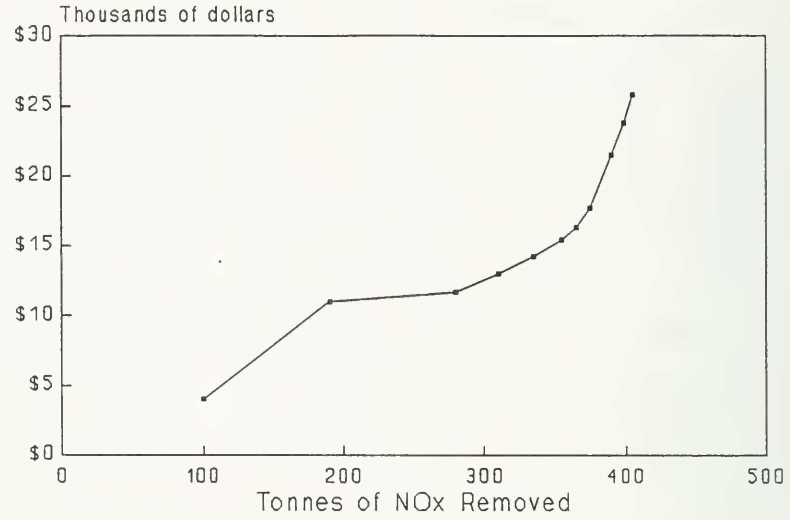

Figure 5.2

Example of an Abatement Cost Curve for Least-Cost Scenario

6 Costs of Abatement Programs

This chapter develops estimates of the costs and effectiveness of various NO_X and VOC abatement strategies by applying the scenarios discussed in Chapter 5 to the costs of emission control technology for the major point-sources within the study area.

6.1 The Effect of Program Design

In designing abatement programs, it is important to take into consideration the distribution of both the benefits and the costs of the control measures. The design of the program may have a significant effect on who will benefit from the program, and who must bear the costs of it.

For example, a program requiring all sources to reduce emissions by a minimum fixed percentage will have the effect of distributing the costs widely. However, it is likely that the actual costs of abatement will be heavier on some industries than others and this approach may fail to take into account the different costs already incurred at each end source. The firms most affected by such a strategy are likely to be different than the firms selected by a strategy aimed at achieving the maximum level of abatement at the least cost.

Similarly, there may be significant differences in the distribution of benefits, depending on the abatement strategy pursued. If the industries affected by the least cost abatement program are located in same region, then the effects of the abatement program will be largely restricted to that and downstream regions - and not necessarily where benefits would be maximized.

The estimated distribution of costs of each strategy can be analyzed and compared at a source, firm, industry, and regional level using the accompanying computer models. Where the costs of ensuring distributional equity across sources (regulating a minimum fixed percent reduction at all sources) are considerably higher than a least cost strategy achieving the same reduction, then serious consideration must be given to the issue of trade-offs between distributional equity and economic efficiency.

The distribution of benefits across regions is more difficult to analyze to any degree of accuracy because of the many factors influencing ozone damages: sunlight, prevailing winds patterns, temperature, etc. In many cases, the most that can be expected is to regulate those sources adjacent to, or upwind of, regions with significant agriculture or population and where excess ozone levels have been measured.

6.2 Volatile Organic Compounds Costs of Control

Analysis of the costs of control for identified sources of VOC emissions were undertaken for the three scenarios described above. Interest rates for annualizing capital equipment costs were varied under each scenario and are reported for each scenario in the accompanying tables.

It was estimated that the application of certain VOC control technologies could result in cost savings for a number of sources. The savings are the outcome of reduced evaporation of fuel and gas from the installation of floating roof tanks. For a total of 12 sources, these cost savings exceeded capital expenditures (annualized at a 10% interest rate) and represented a net savings to the firm at an assumed cost for fuel and gas. As it was not known for each case whether these sources had already installed control technology, it was assumed for the purpose of this analysis that the firms would have acted as cost savers and installed these systems: these options were excluded from further analysis. If the only control technology applicable was floating roof tanks and they resulted in net cost savings, the sources were also excluded from the working database.

6.2.1 Lowest Achievable Emission Rate

The first abatement strategy considered involved requiring all firms to adopt the applicable control technologies from the set examined which would minimize the emissions of VOCs from each of their individual sources. Applying this strategy to all the major sources of VOCs in the study area indicates that an 84.2 % reduction in the emissions from these sources could be achieved - 19 529 of the total of 23 198 tonnes in the study area could be eliminated. The cost of this reduction is estimated at $22 364,000 per annum (1986$)[4], or about $1 150 per tonne with the discount rate at 10%. Costs by industry, establishment, and source vary significantly, due to differences in control technology applicable, individual site characteristics, and economies of scale in controlling emissions. Table 6-1 shows that the cost of supporting a LAER standard ranges from $400 per tonne for the Plastics and Synthetic Resins industry to $4 400 per tonne VOC reduction for the Paint and Varnish industry. Levels of reduction achieved also range widely across different sectors as a result of different control technologies applying to different sources in an industry.

Costs of control by control technology have also been calculated and are presented in Table 6-1 for this scenario. The costs per tonne by technology may appear somewhat misleading.

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[4] All figures are in 1986 dollars unless stated otherwise.

These estimated costs are influenced by the same factors cited above: different costs of control, individual site characteristics, and economies of scale. It may be that the latter two factors have the most impact and that costs of control for a given technology would differ considerably in another application.

Since the choice of technologies is driven entirely by consideration of the removal efficiency, without regard to cost, the reductions are not affected by changes in the discount rate. However, with a 5% discount rate, the total cost would only be about $1 080 per tonne annually, whereas it would rise to about $1 230/tonne if the discount rate were 15%.

Table 6-1

Estimated Costs of VOC Abatement, Lowest Achievable Emission Rate (LAER) (10% Interest Rate), 1986$

By Industry

Industry	Annual Cost	1985 Emissions (tonnes)	Annual Reduction (tonnes)	Annual Reduction Level	Annual Cost per tonne
Petroleum Refineries	$12 887 000	10 826	8 348	77.1%	$1 500
Other Pet. & Coal Products	$5 331 000	6 451	6 446	99.9%	$800
Plastics & Resins	$1 533 000	4 670	3 488	74.7%	$400
Paint & Varnish	$2 014 000	462	462	99.9%	$4 400
Industrial Chemicals	$599 000	789	785	99.5%	$800
Total	$22 364 000	23 198	19 529	84.2%	$1 100

By Technology

Technology:	Annual Cost	1985 Emissions (tonnes)	Annual Reduction (tonnes)	Actual Reduction Level	Annual Cost per tonne
Carbon Treatment	$11 993 988	5 804	5 775	99.5%	$2 100
Steam Flare	$6 829	20	16	80.0%	$400
Thermal Incineration	$6 436 727	10 641	10 641	100.0%	$600
Increased Maintenance	$3 848 914	6 037	2 415	40.0%	$1 600
Piping	$77 201	695	681	98.0%	$100
Total	$22 363 658	23 198	19 529	84.2%	$1 100

NB: Cost figures have been rounded and so may not sum exactly.

6.2.2 Minimum Control Level on all Sources

The next abatement strategy for which costs were estimated was the minimum control level strategy on all sources. Under this scenario, a minimum control level in terms of per cent reduction in emissions is set which all *sources* must comply with. If more than one technology which meets the reduction target applies to a particular source, the least cost of these is selected. If no control technologies apply which meet the target, then the LAER technology which applies is chosen. Thus, for a target level of 100%, the LAER technology is selected for all sources and costs are equivalent to those reported in the section above. The actual reduction levels may be higher than the target level - if the least cost technology has greater reduction efficiencies - or lower than the target level if the LAER technology has a lower removal efficiency than the target level.

This scenario was applied to all VOC emission sources at target reduction levels of 40%, 75%, 80% 90%, 98%, 99%, 99.5% and 100% - corresponding to the reduction efficiency levels of the nine technologies used for VOC control in this study. In all cases except for target levels 99% and above, the costs of control and reduction rates were identical for all sources. This occurs because of both a restricted number of control technologies applying at each source and because control methods with high levels of efficiency are less expensive than control technologies with lower removal efficiencies. For all these cases below a target level of 99%, an 82.2% reduction in emissions is achieved at an overall annual compliance cost of $19 454 000 (at an interest rate of 10%) for a yearly reduction in emissions of 19 059 tonnes of VOCs. The average cost per tonne at this interest rate is $1 020 a year. Table 6-2 provides the distribution of costs and reduction levels across industry sectors and for different technologies at a target level of 80% reduction. Table 6-1 shows the same estimates for a target level of 100% (or 99% and above as discussed above).

6.2.3 Least Cost of Control

This last scenario is perhaps the most interesting as it illustrates the vast range of costs of control pertaining to different sources and presents the most economically efficient costs of control for each level of reduction.

Every control option applying to each source is costed and ordered according to its incremental cost per unit of additional reduction. The concept of incremental costs is discussed in Section 5.3.3 in the preceding chapter. With a corresponding calculation of cumulative reduction in emissions and cumulative cost, the total annual costs of achieving a specified reduction target - or the level of reduction associated with a given annual expenditure - are given for every *economically efficient* reduction level. Total cumulative costs, average costs per tonne, and incremental costs per tonne for representative reduction levels are presented in Table 6-3 (at an interest rate of 10% for annualizing capital expenditures).

The highest level of control obtainable under this scenario is, of course, equivalent to the LAER technology scenario with identical costs of control and the same configuration of technologies. The estimates in Table 6-3 are also presented in graph form in Figure 6-1. Total

Table 6-2

Estimated Costs of VOC Abatement, 80% Minimum Control Level (10% Interest Rate), 1986$

By Industry

Industry	Annual Cost	1985 Emissions (tonnes)	Annual Reduction (tonnes)	Actual Reduction Level	Annual Cost per tonne
Petroleum Refineries	$12 887 000	10 826	8 348	77.1%	$1 500
Other Pet. & Coal Products	$3 712 000	6 451	6 019	93.3%	$600
Plastics & Resins	$1 093 000	4 670	3 456	74.0%	$300
Paint & Varnish	$1 283 000	462	451	97.6%	$2 800
Industrial Chemicals	$479 000	789	785	99.5%	$600
Total	$19 454 000	23 198	19 059	82.2%	$1 000

By Technology

Technology	Annual Cost	1985 Emissions (tonnes)	Annual Reduction (tonnes)	Actual Reduction Level	Annual Cost per tonne
Catalytic Incineration 90%	$670 000	4 642	4 178	90.0%	$200
Carbon Treatment	$13 675 000	6 804	6 770	99.5%	$2 000
Steam Flare	$7 000	20	16	80.0%	$400
Thermal Incineration	$1 172 000	4 983	4 983	100.0%	$200
Increased Maintenance	$3 849 000	6 037	2 415	40.0%	$1 600
Piping	$81 000	712	698	98.0%	$100
Total	$19 454 000	23 198	19 059	82.2%	$1 000

Cost figures have been rounded and so may not sum exactly.

costs of control at different levels of reduction at a range of interest rates are shown in Figure 6-2. This second graph illustrates vividly that costs of control rise dramatically for overall reduction levels of higher than 60%. The graph also indicates that a variation in interest rates has very little impact on total costs of control. This is because: capital costs account for a low proportion of total costs for the selected technologies and so the annualized costs are relatively insensitive to changes in the interest rate.

Incremental costs of control where capital costs are annualized at an interest rate of 10% range from the most cost-efficient source and technology at $75 a tonne to a high of $1.36 million per tonne for the least cost-efficient source.

These results should not simply be considered on their own. As emphasized in Section 6-1, consideration of the costs of control should be go hand-in-hand with a consideration of the

Table 6-3

VOC Least-Cost Abatement Cost Scenario (10% Interest Rate), 1986$

Reduction Level	Incremental Cost (per tonne)	Cumulative Reduction (tonnes)	Cumulative Cost	Average Cumulative Cost (per tonne)
1%	$75	122	$9 100	$75
3%	$78	698	$54 000	$78
6%	$87	1 472	$122 000	$83
10%	$91	2 294	$197 000	$86
15%	$91	3 527	$309 000	$88
21%	$91	4 760	$422 000	$89
24%	$115	5 599	$499 000	$89
31%	$170	7 210	$741 000	$103
36%	$170	8 301	$926 000	$112
40%	$170	9 283	$1 092 000	$118
46%	$276	10 586	$1 378 000	$130
50%	$319	11 544	$1 678 000	$145
55%	$605	12 804	$2 203 000	$172
60%	$2 200	13 868	$3 079 000	$222
67%	$2 300	15 450	$6 726 000	$435
71%	$2 900	16 496	$9 743 000	$591
73%	$2 900	16 939	$11 036 000	$652
80%	$2 900	18 487	$15 555 000	$841
84%	$8 900	19 497	$19 259 000	$988
84.2%	$1 366 900	19 529	$22 364 000	$1 145

benefits. While the incremental costs of control can be estimated on a source-by-source basis, estimating the incremental benefits is much more complex and bound to be less accurate.

Figure 6-3 illustrates a comparison of the costs of a minimum control level applied to all sources and the least cost scenario. The graph shows *actual* levels achieved (not target levels) under the minimum control and least cost scenarios related to the total costs of control. It demonstrates that requiring *any* level of control above zero per cent reduction at all sources with the technologies we have examined will lead to an actual reduction of 82%.[5]. This is because in many instances, the more efficient technologies are either the only technologies which apply to that source or are cheaper than less efficient technologies. If a global reduction of only 60% is sought, this could be achieved at a much lower cost by only requiring a reduction of emissions for a selected group of sources - the least-cost sources.

Figure 6-3 also demonstrates clearly that the highest costs of control for a minimum control level strategy (above a 99% target level) are equivalent to the greatest level of reduction achievable under the least-cost scenario - and equivalent to the costs of control under an LAER

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[5] In practice, many plants would likely achieve emission reductions at lower levels of efficiency through other abatement technologies and control methods.

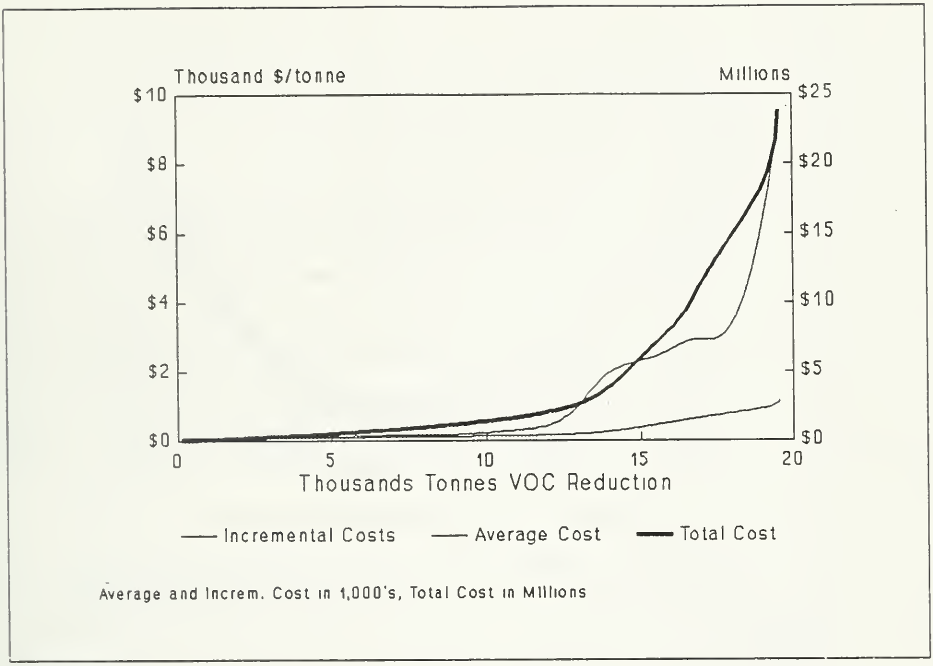

Figure 6-1

VOC Least-Cost Scenario: Incremental, Average, and Total Costs (10% Interest Rate), 1986$

regime.

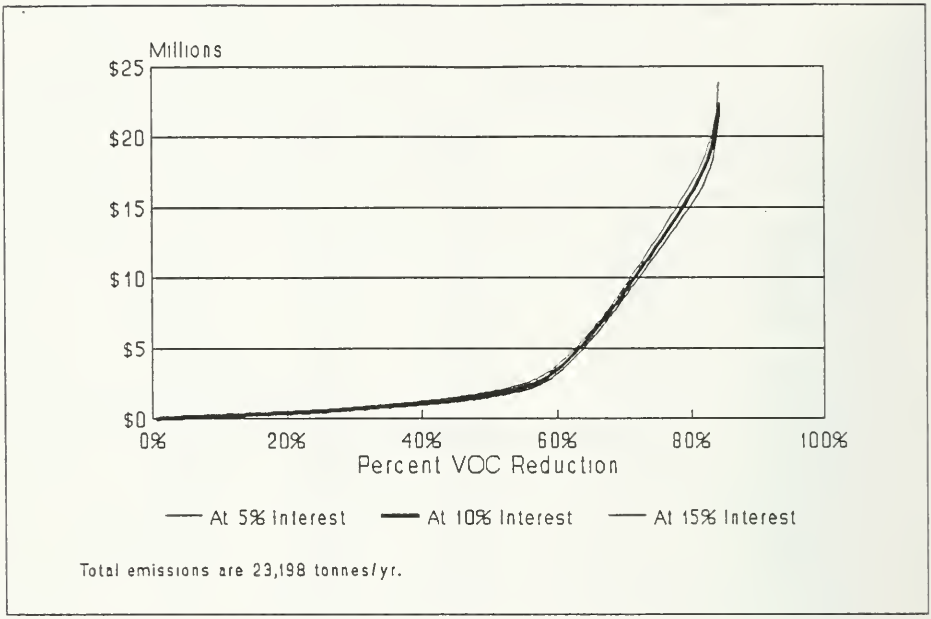

Figure 6-2

Comparison of VOC Least-Cost and Minimum Control Level Abatement Cost Functions (10% Interest Rate), 1986$

6.3 Nitrogen Oxides Costs of Control

Analysis of costs of control for the three scenarios was performed in the same manner as for VOCs described above. The methodology of selection was slightly more complex as there were cases in which a single stack technology applied to a variety of different sources using the same stack at the same time that a process technology applied to only a single source of the group. In the few cases where this applied, selection of the most effective control was made between all applicable options.

As with VOCs, there were a number of instances where control options were estimated to result in cost savings for the source. The two control technologies which resulted in these cost savings are fuel switching (from oil to natural gas) and low excess air firing, where combustion modifications can result in fuel savings of up to 10%. In the database, there were 42 instances where these estimated annual cost savings exceeded the annual costs for control. Because it was not known whether these controls have actually been adopted, the most reasonable assumption

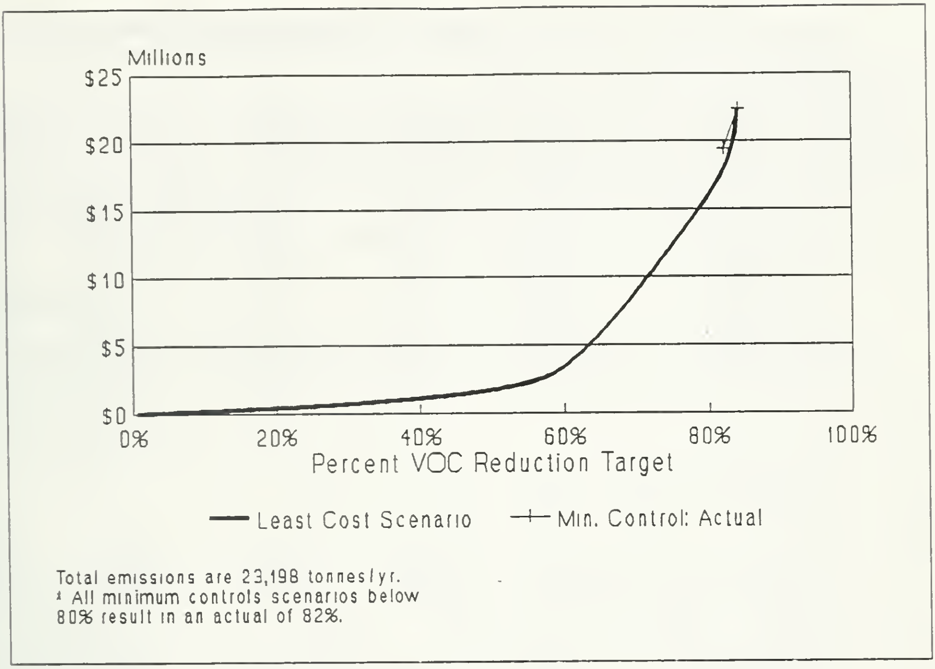

Figure 6-3

VOC Least-Cost Scenario: Total Annualized Costs (Calculated for 5%, 10%, and 15% Interest Rates), 1986$

to make on the basis of these estimates was that the modifications had been adopted for economic reasons. Hence, these control options were excluded from further analysis. However, these sources were not eliminated from the working database as other control options applied in all these cases.

6.3.1 Lowest Achievable Emission Rate

Application of an LAER standard to all sources of NO_x emissions in the study area results in an annual reduction of 26 422 tonnes at a cost of $197 843 000 a year - or $7 500 per tonne.

The LAER reduction of 26 422 tonnes represents 55.1% of the annual emissions of 47 922 tonnes in the study area. Costs of control vary tremendously across sectors - from $3 200/tonne to $98 500/tonne - due to differing costs for different control technologies, economies of scale, and individual site characteristics. As shown in Table 6-4, the lowest costs of control by sector apply to the Electric Utilities sector: Ontario Hydro's generating stations at

Table 6-4

Estimated Costs of LAER for Nitrogen Oxide Abatement (10% Interest Rate), 1986$

By Industry

Industry (OSIC)	Annual Cost	1985 Emissions (tonnes)	Annual Reduction (tonnes)	LAER Reduction (percent)	Annual Cost per Tonne
Petroleum Refineries	$71 034 000	10 239	5 693	55.6%	$12 500
Other Pet. & Coal	$47 518 000	3 483	1 919	55.1%	$24 800
Mixed Fertilizers	$5 194 000	681	375	55.0%	$13 900
Plastics & Resins	$8 771 000	1 168	643	55.0%	$13 600
Paint & Varnish	$2 526 000	46	26	55.8%	$98 500
Soap & Cleaning	$2 991 000	126	69	55.0%	$43 300
Industrial Chemicals	$654 000	15	9	55.0%	$76 900
Other Chemicals	$2 818 000	117	64	55.2%	$43 800
Electric Utilities	$56 337 000	32 046	17 625	55.0%	$3 200
Total	$197 843 000	47 922	26 422	55.1%	$7 500

By Technology

Technology	Annual Cost	1985 Emissions (tonnes)	Annual Reduction (tonnes)	LEAR Reduction (percent)	Annual Cost per Tonne
Staged Combustion	$2 465 000	11	4	40.0%	$570 000
Select. Cat. Red.	$192 284 000	46 574	25 616	55.0%	$7 500
Fuel Switching	$3 095 000	1 337	802	60.0%	$3 900
Total	$197 843 000	47 922	26 422	55.1%	$7 500

NB: Cost estimates have been rounded and so may not sum exactly.

Lakeview and Lambton. Economies of scale are obviously the overriding factor in these results.

Selective catalytic reduction with a reduction efficiency of 55% is the selected technology in the large majority of cases to achieve a LAER standard. Changes in interest rates have a considerable impact on costs, with average costs per tonne removed dropping to $6 100 at 5% and rising to $9 100 at 15%.

6.3.2 Minimum Control Level on all Sources

A minimum control level abatement strategy was applied to all NO_X sources in the study region at target levels of 20%, 40%, 55%, and 60% reflecting the removal efficiencies of the five control technologies applying to these sources. The least cost technology which meets this target is selected for each source; if no technology with high enough removal efficiencies applies to the source, the most efficient applicable is selected. Actual reduction levels may therefore be higher or lower than the target level.

For target removal levels of 20% and 40%, costs of control varied only slightly because low excess air firing was less expensive than alternatives for the few instances where it applied. Actual removal levels of 40.4% for a target level of 40% are achieved at a cost per tonne of

Table 6-5

Estimated Costs of 40% Nitrogen Oxide Minimum Control Scenario (10% Interest Rate), 1986$

By Industry

Industry OSIC	Annual Cost	1985 Emissions (tonnes)	Annual Reduction (tonnes)	Actual Reduction Level	Annual Cost per tonne
Petroleum Refineries	$17 576 000	10 239	4 307	42.1%	$4 100
Other Pet. & Coal Prod.	$5 578 000	3 483	1 394	40.0%	$4 000
Mixed Fertilizers	$1 041 000	681	273	40.0%	$3 800
Plastics & Resins	$1 414 000	1 168	468	40.0%	$3 000
Paint & Varnish	$400 000	46	20	42.7%	$20 400
Soap & Cleaning	$610 000	126	50	40.0%	$12 100
Industrial Chemicals	$160 000	15	6	40.0%	$25 900
Other Chemicals	$695 000	117	47	40.5%	$14 700
Electric Utilities	$34 390 000	32 046	12 818	40.0%	$2 700
Total	$61 864 000	47 922	19 383	40.4%	$3 200

By Technology

Technology	Annual Cost	1985 Emissions (tonnes)	Annual Reduction (tonnes)	Actual Reduction Level	Annual Cost per tonne
Staged Combustion	$3 918 000	5 001	2 001	40.0%	$2 000
Selective Non-Cat Red.	$57 880 000	41 851	16 740	40.0%	$3 500
Fuel Switching	$67 000	1 070	642	60.0%	$100
Total	$61 864 000	47 922	19 383	40.4%	$3 200

Cost figures have been rounded and so may not sum exactly.

$3 200 at 10% interest rate. As shown in Table 6-5, selective non-catalytic reduction is the control method of choice in most cases.

Target control levels of 55% and 60% resulted in identical costs and removal levels because fuel switching did not apply (at removal efficiencies of 60%) to any of the sources where selective catalytic reduction applied (at removal efficiencies of 55%). Removal levels of 55.1% are achieved under this scenario, as all sources to which selective non-catalytic reduction applied with to selective catalytic reduction at an average cost over double that for SNR. A minimum control level of 100% yields results similar to the LAER scenario as shown in Table 6-4.

A comparison of the costs of these target levels against least costs of achieving a selection of reduction levels is illustrated in Figure 6-6.

6.3.3 Least Cost of Control

The least cost scenario selects control options sequentially in order of lowest incremental cost. These results show the most economically efficient costs of control for each level of reduction as control measures are applied selectively to each source.

Table 6-6

Least-Cost Nitrogen Oxide Abatement Cost Function (10% Interest Rate), $1986

Reduction Level (percent)	Incremental Cost (per tonne)	Cumulative Reduction (tonnes)	Cumulative Cost	Average Cumulative Cost (per tonne)
1	$4	560	$2 088	$4
2	$20	1 120	$13 400	$12
4	$56	1 749	$48 500	$28
5	$1 300	2 282	$355 700	$156
6	$1 600	2 890	$1 265 200	$438
22	$2 100	10 556	$17 600 300	$1 700
26	$2 800	12 497	$23 019 300	$1 800
38	$3 400	18 289	$42 616 200	$2 300
44	$3 600	21 049	$52 654 900	$2 500
49	$5 800	23 260	$65 329 700	$2 800
50	$16 100	23 969	$71 939 500	$3 000
53	$23 300	25 402	$103 077 900	$4 100
54	$73 700	26 117	$128 400 600	$4 900
55	$271 400	26 356	$159 495 100	$6 100
55.14	$6 660 800	26 422	$197 843 300	$7 500

Table 6-6 displays total, incremental, and average costs for representative reduction levels. The highest level of control for each scenario corresponds to LAER levels estimated for each of the previous two strategies. This table and Figure 6-4 show that incremental costs of control rise rapidly just above 23 000 tonnes reduction - or a global reduction of 48% for the study area - as selective catalytic reduction is adopted by an increasing number of sources. Figure 6-5 shows this trend for interest rates of 5%, 10%, and 15%, also illustrating the relatively wide range of total costs resulting from interest rate changes.

Figure 6-6 provides a comparison of total costs for the least cost and minimum control level scenarios and shows that cost differences at a 40% target level are relatively small, owing to the cost-effectiveness of selective non-catalytic reduction technology for most sources.

This figure demonstrates that there is little difference between the total costs of a minimum control strategy at 40% (and, of course, at the LAER level) but that the costs of a minimum control strategy at 20% are about three times the costs of a least cost strategy at this level of global reduction. Applying a least cost strategy can be difficult because of the inaccuracies that are bound to be present at a source level even in a detailed study such as this.

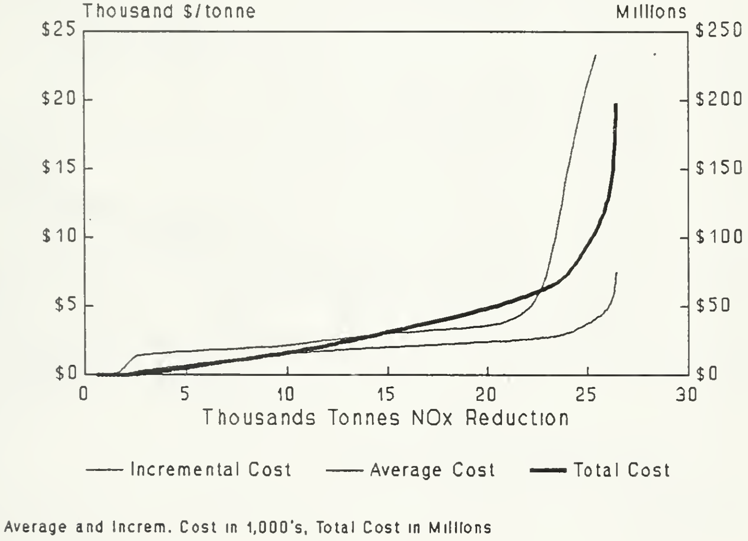

Figure 6-4

Nitrogen Oxide Least-Cost Scenario: Incremental, Average, and Total Costs (10% Interest Rate), 1986$

Alternate strategies with a total price-tag below the minimum control level on all sources but above the least cost strategy are: minimum control level (or LAER) on sources emitting more than a certain level; minimum control level or LAER on industries within a particular subsector or region; minimum control level or LAER on selected establishments identified as having low costs of control. At each of these levels, the regulatory requirement can be a minimum level of reduction on all sources (for instance, all sources at a plant must be controlled) or minimum level of reduction for global emissions (only the least-cost sources at a plant would be selected by managers to achieve the same overall level of reduction). All these strategies can be analyzed with the accompanying computer models and the instructions included.

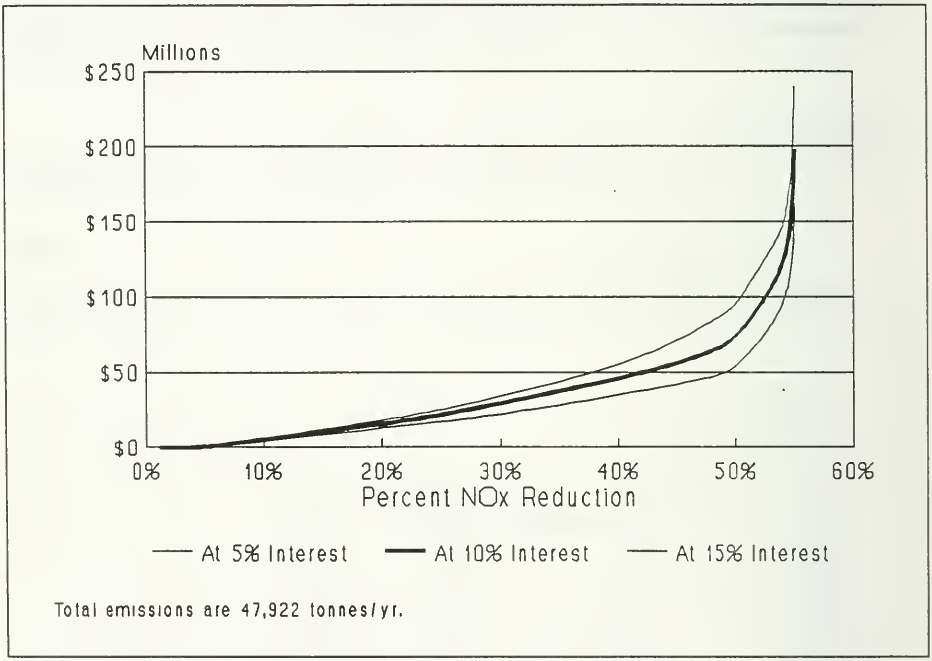

Figure 6-5

Nitrogen Oxide Least-Cost Scenario (Total Annualized Costs Calculated at 5%, 10% and 15% Interest Rates), 1986$

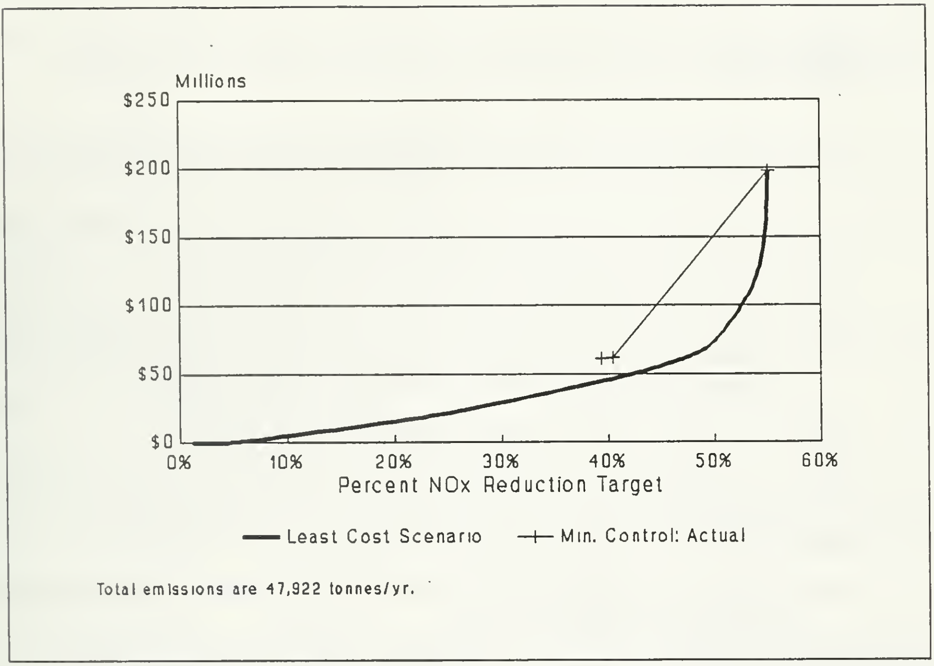

Figure 6-6

Nitrogen Oxide Least Cost and Minimum Control Level Estimated Cost Comparison at 10% Interest Rate, 1986$

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Appendix A

Industrial and Emission Sector Classification

The Ontario Ministry of Industry, Trade, and Technology maintains its own version of the standard industrial classification called the Ontario Standard Industrial Classification (OSIC). This is the form of industrial classification used in the Ontario Emissions Inventory. They differ from the Canadian Standard Industrial Classification in many areas.

This study examined emission sources belonging to the following industrial sectors as defined by the OSIC. This aggregation is somewhat different from that used by the Air Resources Branch (ARB) of the Ontario Ministry of Environment. The ARB aggregation is discussed in Appendix C.

Petroleum Refining	
3650	Petroleum Refineries
3690	Other Petroleum and Coal Products
Chemical Industries	
3710	Explosives and Ammunition
3720	Mixed Fertilizers
3730	Plastics and Synthetic Resins
3740	Pharmaceuticals and Medicines
3750	Paint and Varnish
3760	Soap and Cleaning Compounds
3770	Toilet Preparations
3780	Industrial Chemicals
3790	Other Chemical Industries
Electric Generating Plants	
5720	Electric Utilities

Tables 2-1 and 2-2 provide an aggregation by major sector of industrial emissions from all sources for the study areas listed in the point-source emissions inventory. The following aggregations were used:

OSIC Codes	*Major Sectors*
0000 - 0990	Primary
1010 - 1530	Food Processing (incl. Alcohol & Tobacco)
1610 - 1790	Rubber and Leather
1830 - 2490	Textiles and Clothing
2510 - 2890	Wood and Paper (incl. Furniture)
2910 - 3090	Primary Metal and Fabricating
3110 - 3290	Machinery and Vehicles
3310 - 3390	Electrical Products
3410 - 3590	Non-Metal Minerals
3650 - 3690	Petroleum Refining
3710 - 3790	Chemical Products
3810 - 3990	Misc. Manufacturing
4040 - 4090	Construction
5010 - 5480	Transport and Communication
5720	Electric Utilities
5740 - 5790	Other Utilities
6020 - 7370	Trade
8010 - 9990	Services

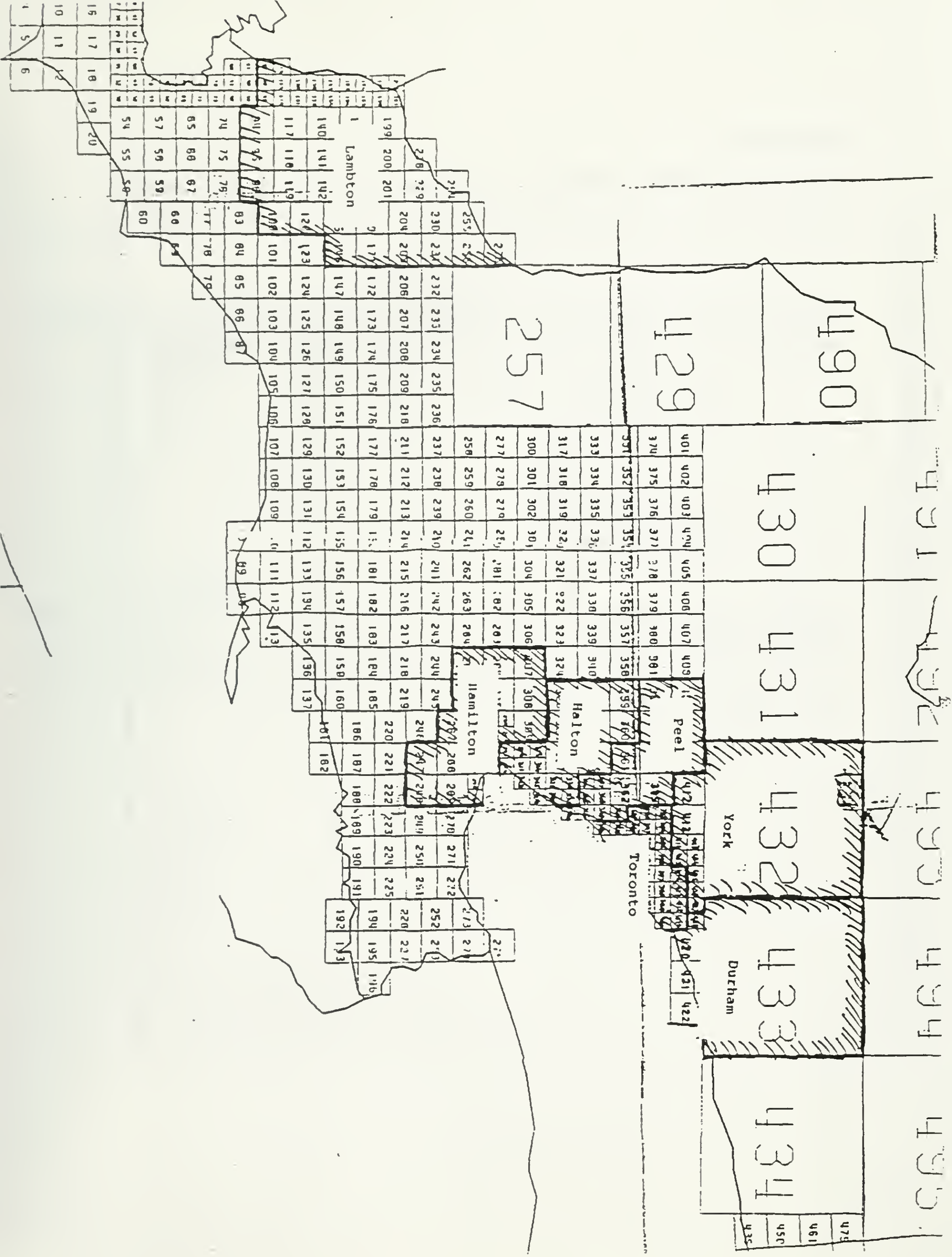
Tables C-1 and C-2 in Appendix C show the same aggregation used by the Air Resources Branch of the MOE in order to facilitate comparisons with provincial totals.

Appendix B Delineation of Study Regions

The method used to delineate the study region boundaries is described briefly in Section 2.1.2 of the report. This appendix provides more detail on the specific regions included together with a map illustrating the boundaries of each area.

Emission sources are classified according to geographical region in the emissions inventories by Universal Transverse Mercator (UTM) grid cells. The grid cells used are 5 km by 5 km in area for the Windsor - Lake St. Clair - Sarnia and the Hamilton - Toronto regions, 10 km by 10 km for much of the rest of southern Ontario, and 50 km by 50 km for Ontario north of approximately 44°00'. The regions were selected to correspond as closely as possible to regional municipal boundaries but, because the grid cells do not follow municipal or regional boundaries, only an approximation to these boundaries could be made.

Seven municipal regions comprise the study areas: Lambton, Hamilton, Halton, Peel, Toronto, York, and Durham. These areas are outlined on the map with UTM grid cells on the following page.


Lambton
257
429
490
430
431
432
433
434
Hamilton
Halton
Peel
York
Toronto
Durham

Appendix C

Air Resources Branch Sector Categories

Tables C-1 and C-2 present a listing of OSIC codes classified into the nine major categories of the ARB classification used in Tables 2-1 and 2-2 of the study. These classes are:

0	Miscellaneous Point Sources
1	Electric Utilities
2	Non-Ferrous Smelters
3	Petroleum Refineries
4	Pulp and Paper Industries
5	Other Primary Metals
6	Chemical Industries
7	Other Manufacturers
8	Mining

Data and estimates presented in these Tables are derived from values found in the Ontario Emissions Inventory during 1988.

The categorization found in Tables C-1 and C-2 is different from that used in the rest of the report - which is described in Appendix A.

Table C-1

1985 Point-Source NO_x Emissions by Sector and Region - Air Resources Branch Classification

Tonnes\Year

Sector	Province	Study Region	Lambton	Hamilton	Halton	Peel	Toronto	York	Durham
Electric Utilities	94 600	32 104	18 458	0	0	13 646	0	0	0
Non-Ferrous Smelters	4 914	0	0	0	0	0	0	0	0
Other Primary Metals	14 198	7 486	0	1 833	5 568	0	82	4	0
Petroleum Refineries	17 731	16 161	12 109	0	1 153	2 850	50	0	0
Pulp & Paper	11 713	275	0	30	0	0	245	0	0
Chemicals	9 937	6 202	5 323	231	0	0	644	3	0
Other Manufacturers	18 199	9 720	2 947	1 333	265	0	4 688	9	477
Mining	1 189	0	0	0	0	0	0	0	0
Miscellaneous	4 206	2 423	81	663	0	0	1 632	17	31
TOTAL	176 686	74 371	38 918	4 090	6 986	2 850	20 986	33	508

Percent of Provincial Total

Sector	Province	Study Regions	Lambton	Hamilton	Halton	Peel	Toronto	York	Durham
Electric Utilities	53.5%	18.2%	10.4%	0.0%	0.0%	0.0%	7.7%	0.0%	0.0%
Non-Ferrous Smelters	2.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Primary Metals	8.0%	4.2%	0.0%	1.0%	3.2%	0.0%	0.0%	0.0%	0.0%
Petroleum Refineries	10.0%	9.1%	6.9%	0.0%	0.7%	1.6%	0.0%	0.0%	0.0%
Pulp & Paper	6.6%	0.2%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Chemicals	5.6%	3.5%	3.0%	0.1%	0.0%	0.0%	0.4%	0.0%	0.0%
Other Manufacturers	10.3%	5.5%	1.7%	0.8%	0.2%	0.0%	2.7%	0.0%	0.3%
Mining	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Miscellaneous	2.4%	1.4%	0.0%	0.4%	0.0%	0.0%	0.9%	0.0%	0.0%
TOTAL	100.0%	42.1%	22.0%	2.3%	4.0%	1.6%	11.9%	0.0%	0.3%

Percent by Region

Sector	Province	Study Regions	Lambton	Hamilton	Halton	Peel	Toronto	York	Durham
Electric Utilities	53.5%	43.2%	47.4%	0.0%	0.0%	0.0%	65.0%	0.0%	0.0%
Non-Ferrous Smelters	2.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Primary Metals	8.0%	10.1%	0.0%	44.8%	79.7%	0.0%	0.4%	11.6%	0.0%
Petroleum Refineries	10.0%	21.7%	31.1%	0.0%	16.5%	100.0%	0.2%	0.0%	0.0%
Pulp & Paper	6.6%	0.4%	0.0%	0.7%	0.0%	0.0%	1.2%	0.0%	0.0%
Chemicals	5.6%	8.3%	13.7%	5.7%	0.0%	0.0%	3.1%	10.2%	0.0%
Other Manufacturers	10.3%	13.1%	7.6%	32.6%	3.8%	0.0%	22.3%	27.8%	94.0%
Mining	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Miscellaneous	2.4%	3.3%	0.2%	16.2%	0.0%	0.0%	7.8%	50.4%	6.0%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Notes:

Data aggregated from 1985 ARB Ontario Emissions Inventory as of 1988.

Sector totals may differ from those in Chapter 2 because of different sector aggregations.

Table C-2

1985 Point-Source VOC Emissions by Sector and Region - Air Resources Branch Classification

- Tonnes per Annum -

Sector	Province	Region	Lambton	Hamilton	Halton	Peel	Toronto	York	Durham
Electric Utilities	442	178	124	0	0	0	54	0	0
Non-Ferrous Smelters	35	0	0	0	0	0	0	0	0
Other Primary Metals	6 808	3 073	0	1 578	1 171	0	00	125	0
Petroleum Refineries	19 445	19 340	9 296	0	2 292	7 688	64	0	0
Pulp & Paper	6 200	4 094	0	0	0	0	4 94	0	0
Chemicals	19 245	18 874	15 259	116	0	0	3 00	0	0
Other Manufacturers	17 362	10 252	1 044	3 997	1 730	0	3 58	19	304
Mining	13	0	0	0	0	0	0	0	0
Miscellaneous	1 636	703	181	373	0	0	45	0	4
TOTAL	71 188	56 514	25 904	6 063	5 193	7 688	11 13	144	308

Percent of Provincial Total

Sector	Province	Region	Lambton	Hamilton	Halton	Peel	Toronto	York	Durham
Electric Utilities	0.6%	0.2%	0.2%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Non-Ferrous Smelters	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Primary Metals	9.6%	4.3%	0.0%	2.2%	1.6%	0.0%	0.3%	0.2%	0.0%
Petroleum Refineries	27.3%	27.2%	13.1%	0.0%	3.2%	10.8%	0.1%	0.0%	0.0%
Pulp & Paper	8.7%	5.8%	0.0%	0.0%	0.0%	0.0%	5.8%	0.0%	0.0%
Chemicals	27.0%	26.5%	21.4%	0.2%	0.0%	0.0%	4.9%	0.0%	0.0%
Other Manufacturers	24 4%	14 4%	1.5%	5.6%	2.4%	0.0%	4 4%	0.0%	0.4%
Mining	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Miscellaneous	2.3%	1.0%	0.3%	0.5%	0.0%	0.0%	0.2%	0.0%	0.0%
TOTAL	100.0%	79 4%	36 4%	8.5%	7.3%	10.8%	15.8%	0.2%	0.4%

Percent by Region

Sector	Province	Region	Lambton	Hamilton	Halton	Peel	Toronto	York	Durham
Electric Utilities	0.6%	0.3%	0.5%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%
Non-Ferrous Smelters	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Primary Metals	9.6%	5.4%	0.0%	26.0%	22.5%	0.0%	1.8%	86.7%	0.0%
Petroleum Refineries	27.3%	34.2%	35.9%	0.0%	44.1%	100.0%	0.6%	0.0%	0 0%
Pulp & Paper	8.7%	7.2%	0.0%	0.0%	0.0%	0.0%	36.5%	0.0%	0.0%
Chemicals	27.0%	33.4%	58.9%	1 9%	0.0%	0.0%	31.2%	0.1%	0.0%
Other Manufacturers	24.4%	18.1%	4.0%	65.9%	33.3%	0.0%	28 2%	12.9%	98.6%
Mining	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Miscellaneous	2.3%	1.2%	0.7%	6.1%	0.0%	0.0%	1.3%	0.3%	1 4%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100 0%	100 0%

Notes:

Data from the 1985 Ontario Emissions Inventory as of 1988

Sector totals differ from those in Chapter 2 because of different sector aggregations.